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Water-Supply and Irrigation Paper No. 71 Series I, Irrigation, 13

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

IRRIGATION SYSTEMS OF TEXAS

BY

THOMAS U. TAYLOR

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 1, 1902.

SIR: I have the honor to transmit herewith a paper entitled Irrigation Systems of Texas, by Thomas U. Taylor, professor of civil engineering at the University of Texas. This paper contains the results of field work carried on by Professor Taylor through several years in connection with the measurement of the principal rivers of Texas and the investigation of the best methods of utilizing the water resources of the State. I recommend it for publication in the series of pamphlets on Water Supply and Irrigation.

A report on the same subject was prepared in 1897 by Mr. William F. Hutson, and printed as Paper No. 13 of this series. Since that time considerable development has taken place in the utilization of water in Texas, and the ground has been gone over with greater thoroughness, resulting in obtaining a larger and more complete presentation of the subject.

In the present report Professor Taylor has discussed the principal irrigation systems in general geographic order, and has given statistics as to the location, cost, and benefits of the devices for obtaining water. He has also devoted some attention to the irrigation of rice, a business in which large amounts of capital are being invested. There has been appended a brief statement of the laws governing irrigation in the State of Texas, also some of the facts obtained from the recent census investigation.

Yours, with respect,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATION SYSTEMS OF TEXAS.

By THOMAS U. TAYLOR.

INTRODUCTION.

The practice of irrigation in Texas is of considerable antiquity, especially in the western end of the State, along the Rio Grande, where the early Spanish conquerors established settlements, and their descendants, the Mexicans, have maintained possession of the soil for centuries. At San Antonio are ditches whose origin is lost in local tradition, having probably been built to carry water to the grounds surrounding the missions. It is only in comparatively recent years, however, that particular attention has been drawn to the matter, and the importance of the development of the State through irrigation has been appreciated by the public. Already agriculture by means of an artificial supply of water is being practiced in nearly every portion of the State, the greatest increase in acreage being in the rice-growing districts in the southeastern quarter. The figures obtained at the Eleventh Census (1889) and Twelfth Census (1899) illustrate the rapid increase in acreage and the wide extent to which irrigation is now employed.

For most of the land water is obtained by gravity systems of ditches—that is to say, by means of channels through which the water flows from some source at a higher elevation. In many places, however, it is impossible to bring water to the surface of the ground in this way, and it must be lifted or pumped by some mechanical device. For this purpose windmills are most commonly used. West of the one-hundredth meridian north of San Antonio the cattle country of Texas stretches almost unbroken for from 200 to 500 miles. To supply water for the ranches which do not border on or include a flowing stream the windmill has become a most potent factor. In addition, a few localities, like oases, have everlasting springs that rise with surprising suddenness either from the foothills or from the baked prairies. These are in nearly all cases utilized to convert the otherwise unproductive soil into crop-bearing farms. While the old Mexican methods of irrigation are still in use in many localities, with their consequent waste of water, they have been accompanied by few disappointments or heartburnings.

Irrigation in Texas has not escaped the booming influence of the land agent or the subtle promoter. Nearly every county in the western part of the State through which flowing streams course their way has on its maps the sinuous tracings of irrigation systems, while the secretary of state has issued hundreds of charters for systems that fortunately got no further than the charter stage. Some of the promoters, however, with the seductive phrase "modern methods," have formed companies, constructed canals costing hundreds of thousands of dollars, and sold lands, upon flattering prospectuses, to honest and would-be settlers without the slightest data of the available water supply. The collapse of many enterprises and the loss of much money have made the public timid, with the result that two amendments to the State constitution, which carried with them permission to bond certain districts, have been overwhelmingly defeated. The first was prepared in 1897, and under its terms certain districts could, by a majority vote of the landowners, issue bonds for the purpose of constructing irrigation systems. The second amendment, which was voted on in the fall of 1900, carried with it power by virtue of which the people of the Wichita and adjacent districts could issue bonds for the purpose of constructing an immense irrigation system in the Wichita Valley.

With sufficient hydrographic data, however, there was and is no occasion for disappointment; but obtaining these data is a process entirely too slow for the irrigation agent, the promoter, and the developer, and the result is marked by wrecked hopes in many localities. The year 1900, a very wet one, furnished excellent data upon which flattering prospects could be held out to prospective rice farmers, as all streams, bayous, and lakes were full of water and the rainfall was so abundant that only a small amount of artificial watering was required. Result, an excellent crop of rice, a large part of which was watered by Providence. The year 1901, however, was a striking contrast to 1900, for there was no good soaking rain from the time of the Galveston storm, September 8, 1900, until the latest sowing of 1901. The coast country was dry, water was low, and new canals were untried. No two years could emphasize more clearly the need of caution in placing dependence upon a water supply. In the latter year many of the bayous were drawn upon for an amount of fresh water that so lowered their surface level that the salt water of the lower sections backed into them and impregnated the supply. To counteract this, at some places dams have been constructed to check the inflow of sea water.

The irrigation systems of the State have been divided into the following groups: (1) The trans-Pecos systems; (2) the Pecos Valley systems; (3) the Edwards Plateau systems; (4) the systems at San Antonio and vicinity; (5) the systems along Lower Nueces River, Lower Rio Grande, and Leona River; (6) the Colorado Valley sys-

tems; (7) the systems north of Colorado River; and (8) the rice irrigation systems.

The two dry years of 1901 and 1902 have called attention to the necessity of irrigation in what has been heretofore called middle Texas. Farmers are realizing the efficiency of an irrigation system to be put into operation when the rainfall is not sufficient for agricultural purposes. Slowly irrigation for ordinary crops takes its way eastward in Texas. It is now on the Brazos, and another dry season will take it to the Trinity River.

In the preparation of this paper valuable assistance has been rendered by Lester G. Bugbee, instructor in history in the University of Texas; Willard H. Denis, observer at Pecos; Judge O. W. Williams, of Fort Stockton; the late S. C. Dobbins, civil engineer, and T. L. Smith, civil engineer, of Columbia. The writer has also frequently consulted Water-Supply Paper No. 13, prepared by W. F. Hutson.

TRANS-PECOS SYSTEMS.

The portion of the State west of Pecos River is commonly known as trans-Pecos Texas. It is a peculiar country, rough and mountainous, with few perennial streams. The storm waters rush out upon the lowlands and are rapidly absorbed in the sandy plains, from which the mountains rise abruptly as isolated peaks or ranges. The soil of the plains is of remarkable fertility, and when watered produces abundantly. Irrigation away from the creeks, however, is practicable only by means of storage reservoirs holding the storm waters. Reservoir sites occur in many places, and several of them have been mapped by the topographers of the Geological Survey. Trans-Pecos Texas is bounded on the west and south by the Rio Grande, from which water is at present taken for irrigation mainly in the vicinity of the Big Bend. The following irrigation systems occur in the trans-Pecos region: (1) The El Paso Valley systems; (2) the Toyah Creek systems; (3) the Fort Stockton systems; (4) the Santa Lucia systems; and (5) the Big Bend systems.

EL PASO VALLEY.

Franklin canal.—At El Paso the principal canal is that owned by the Franklin Irrigation Company. It was begun in 1889 and completed in 1891. Later the affairs of the company were placed in the hands of a receiver, and the property was bought at a receiver's sale by Thomas Worthington, of Manchester, England, the trustee for the bondholders. The canal begins 1 mile northwest of El Paso, and runs in a general southeasterly direction for 29 miles. (See fig. 1.) At the beginning its width is 30 feet, but it gradually diminishes to 15 feet at Fabens, where it returns to the Rio Grande. Water is diverted by a masonry wing dam extending diagonally up the river about 300

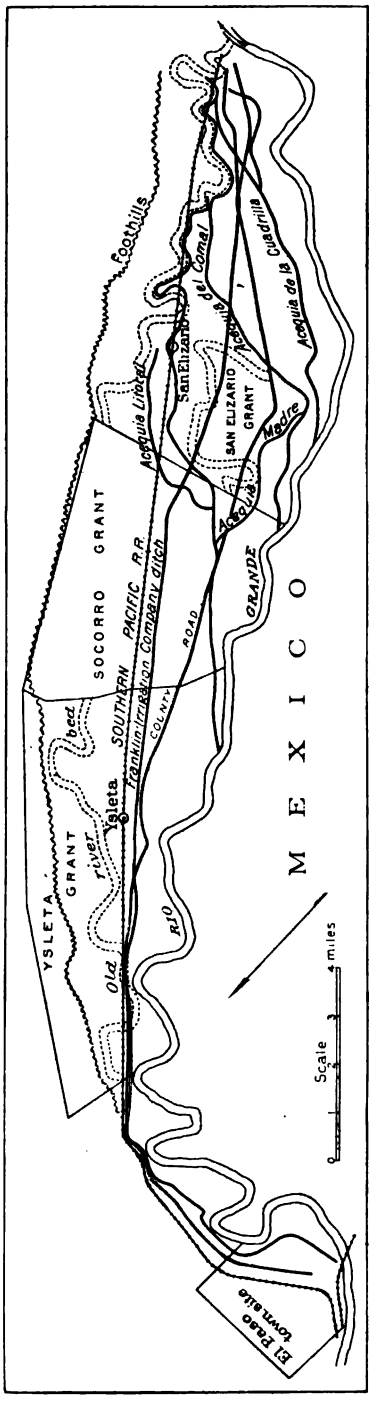

FIG. 1.—Map showing irrigation systems in El Paso Valley.

feet and about halfway across, as shown in Pl. I. The original cost was approximately $150,000, and about $70,000 has since been expended for protection from overflows and for repairs. The water rights under the new management have not yet been issued. The yearly water rental was $2 an acre. The canal was designed to cover 30,000 acres. During 1896, 3,000 acres were irrigated from it, but since that time practically no land has been served from this ditch, on account of lack of water in the Rio Grande.

Ysleta, Socorro, and San Elizario ditches.—There are three old Mexican ditches taken from the Rio Grande below El Paso, on the American side, on grants of land made to the inhabitants of Ysleta, Socorro, and San Elizario, capable of irrigating from 1,000 to 1,200 acres each. (See fig. 1.) The ditch on the Ysleta grant was taken out of the Rio Grande about 3 miles south of the present station of Ysleta (not the old town of Ysleta), and continued through the Socorro and San Elizario grants, following the banks of the old river bed after passing the present station of San Elizario. The total length of the main acequia was about 10 miles, and the two branches, the Acequia Littoral and the Acequia Madre, were 4 and 3 miles long, respectively. The Acequia del Comal took its water from the Rio Grande about 15 miles below El Paso, on the lower part of the Socorro grant. It followed the general course of the river for 2½ miles, then ran almost due east for 3½ miles, and finally

WING DAM OF EL PASO IRRIGATION COMPANY.

deflected to follow the banks of the old river bed. Its total length was about 10 miles. The Acequia de la Cuadrilla took its water from the Rio Grande 2 miles below the intake of the Acequia del Comal. Its total length was about 9 miles.

These Mexican ditches are capable of irrigating about 3,000 acres, but the flow of the Rio Grande at El Paso has been so unreliable for several years that it was impossible to base any calculations upon it. A reliable storage reservoir in the mountains above El Paso would serve during its life to make the whole El Paso Valley on both sides of the river for 30 miles one of the most productive countries in the world, for it possesses an unrivaled climate and is capable of producing fruits with a flavor that easily commands for them the highest price wherever they go. The total area on the American side that could be brought into active production would be not less than 40 square miles.

Irrigation has been practiced here probably longer than in any other part of the United States. The old Spanish records show that when this pass was first reached by the exploring party of Coronado, villages of Indians were found on the Mexican side, on the site of the present town of Jaurez, and on the American side at Ysleta and below. These Indians had a system of irrigation of seeming great antiquity, which has been followed by the descendants of the aborigines and their conquerors for three hundred and fifty years.

During the spring of 1897 the large canal was damaged by the flood that submerged so large a portion of the town of El Paso. This flood reached its greatest height on May 26, and quickly subsided. The banks were badly cut, and in some places the canal was completely obliterated. The truck gardens and orchards near the city were flooded and damaged, a layer of mud about 3 inches thick being deposited over the surface. It was noticeable that while most trees withstood the flooding comparatively well, the peach trees were almost uniformly killed. Fortunately for the farmers lower down, a portion of the river cut for itself a new channel, curving inward, crossing the canal, and then recrossing it at the last point at which the banks were damaged. In this way they have been supplied with water and are able to save their crops, which otherwise would be ruined.

TOYAH CREEK.

Toyah Creek rises in natural springs about 40 miles southwest of Pecos. These springs are mainly in section 256, patented by the State of Texas to Antonio Ball. They are in a flat valley, hemmed in by a horseshoe curve of the Davis Mountains. About 3 miles northwest is Phantom Lake. It is stated by close observers that the waters of the creek and lake are of the same composition and general character, and it is probable that the latter is on the underground stream that issues from the earth in the Toyah Springs.

The largest of the Toyah Springs is oval shaped, and is about 100 feet long by 60 feet broad. Its water level in the spring varies with the condition of the weeds and long grass, and also with the weather. The discharge as measured by the writer on September 5, 1900, was 46 second-feet. A large percentage of the water is deflected

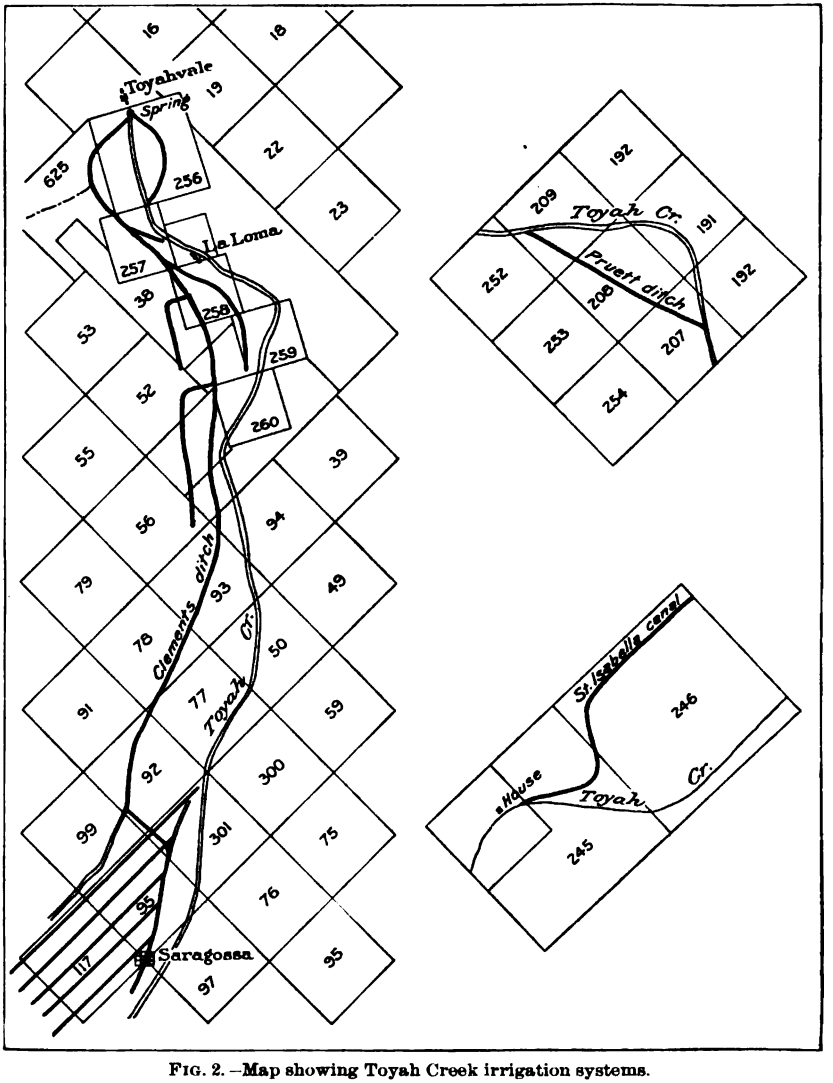

FIG. 2.—Map showing Toyah Creek irrigation systems.

into the ditch of Toyah Creek Irrigation Company. The flow of the spring is equal to about 8 heads, a head being defined as the amount of water that flows through an opening 1 foot square, the upper edge of the opening being 4 inches below the water surface. There is an unverified and hazy tradition that the flow once amounted to 12 heads, but this is seriously doubted.

For several miles the creek skirts the foothills of the Davis Mountains, and in addition to the well-known springs mentioned is fed by small invisible springs and by seepage. It empties into Toyah Lake, a large alkali flat depression about 35 miles from Toyahvale and about 12 miles south of Pecos.

In all there are five ditches taken out of Toyah Creek: (1) The Clements or Murphy, 9 miles long, taken out of Toyah Spring, on the south side, and irrigating about 1,500 acres; (2) the Giffin, 1 mile long, taken out of Toyah Creek, on the north side, and irrigating about 400 acres; (3) the Saragossa, 2 miles long, taken out on the south side of the creek, about 6 miles below Toyah Spring, and irrigating 1,500 acres (this is included in the Clements system); (4) the St. Isabella ditch, which irrigates about 700 acres and is 2 miles long, being taken out on the north side of the creek, 19 miles below Toyah Spring; and (5) the Pruett ditch, 2 miles long, headgate 26 miles below Toyah Spring, on the south side, which irrigates about 300 acres. The location of the ditches is shown in fig. 2. The crops raised are mostly corn, wheat, Kafir corn, and sweet potatoes. From Toyahvale to Saragossa the irrigation has been very efficient. A half mile above Saragossa, on the main Saragossa ditch, is Clements's grain and flour mill, an adobe and timber structure, at which there is a fall of 12 feet.

The main irrigation ditch leading from the largest of the Toyah springs (now known as the Clements or Murphy ditch) was projected as early as 1875, but the ditches of the Saragossa and the Toyah Creek companies were chartered in 1875 and 1876. Afterwards the companies passed through various ownerships and changes until 1894, when Mr. E. Clements obtained all the rights and ownership of the Saragossa Company ditch, and in 1895 he obtained a controlling interest in the Toyah Creek ditch. The Saragossa ditch was taken out of Toyah Creek about 6¼ miles below the Toyah Springs and about 1¾ miles above the town of Saragossa. Both ditches are now operated under the Clements management, a lateral connecting them. The original Saragossa ditch was taken out probably as early as 1869, at a point where the bed of the creek ended in rather swampy lands. These lands are now in the Saragossa farm. From the best evidence obtainable the flow of the Saragossa Spring was about 15 second-feet, and it was the largest affluent of Toyah Creek below section 256.

Toyahvale is about an eighth of a mile west of the Toyah Springs; La Loma is about 1 mile below the head spring, on the right bank; India (known as Brogado P. O.) is about 4 miles below the Toyah Springs, on the right bank; while Saragossa is 9 miles below the head spring, on the right bank of the creek.

FORT STOCKTON.

Comanche Creek rises near Fort Stockton, in a clear and bold spring. In 1899 its flow, as determined by measurement, was 70 second-feet. The waters of the creek were first used for irrigation

in 1868, when Cæsario Torres irrigated land belonging to Gen. Hatch and others. In 1870 the United States Government irri about 100 acres, most of which was used for a garden for the po

In fig. 3 are shown four irrigation ditches taken out of the cr two on the right or east side and two on the left or west side.

Garza ditch and Comanche Creek Irrigation Company dit The ditches on the right side of Comanche Creek are known as Garza ditch and the Comanche Creek Irrigation Company's d both of which are owned by the Southwestern Irrigation Compa The former is taken out about 3 miles and the latter 3¼ miles belo

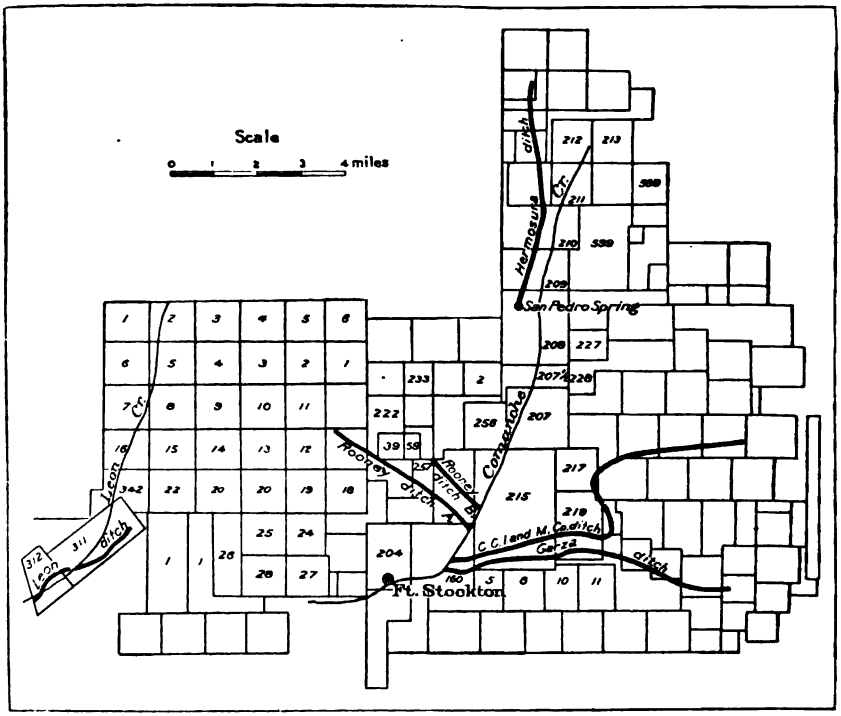

FIG. 3.—Map showing Fort Stockton irrigation systems.

Fort Stockton. A loose dam, made of cottonwood logs and turf, raises the water into the Garza ditch, which is 6 miles long and is used to convey water to cattle ranches. From 600 to 800 acres are irrigated from the lowest (Comanche Creek Irrigation Company) ditch, 400 acres being in alfalfa.

Rooney ditches.—Two ditches, known as the Rooney ditches, and marked A and B in fig. 3, are taken out on the left side of the creek. They were constructed in 1876 and 1877. Ditch A is about 4 miles long, and is taken out about a half mile below the head of the Garza ditch. The Rooney ditches can irrigate 6,000 acres. In 1900 they actually irrigated 1,360 acres, 900 acres being in corn, 400 acres in

cotton, and 60 acres in alfalfa. On ditch A is located the mill belonging to Rooney & Butts, of Fort Stockton. The fall at the gin is 12 feet, and 12 horsepower is developed by a 24-inch Leffel turbine.

Hermosura ditch.—The Hermosura ditch, owned by J. H. Crawford, is 7 miles east of Fort Stockton and receives its waters from the San Pedro Spring, which is in section 208 of the Texas land office map. The flow of the spring is about 4 second-feet, and from it Mr. Crawford irrigates 160 acres of land.

Seven miles west of Fort Stockton Mrs. Royall irrigates 260 acres from the Leon Spring.

SANTA LUCIA.

The Santa Rosa Spring is in section 68 of the Texas land office map. It comes out in a bold stream of about 10 second-feet volume, and flows in the ditch constructed for its control. It is 4½ miles north of the post-office at Santa Lucia, the office being located at the home of Thomas L. Ray, the largest user of the Santa Rosa water for irrigation purposes. The water is under the control of the Pecos River Company, and each irrigator pays 50 cents per year per acre for sufficient for his crops. Mr. Ray planted cottonwoods along the ditches, and now his farm is bordered on the north and west sides by stately trees that can be seen for 20 miles. He lives in section 104, and irrigates 100 acres. Mr. Levi A. Scott lives 2 miles north of Santa Lucia, and irrigates 60 acres from the Santa Rosa (spring) ditch. The crop raised is mostly alfalfa, and when visited in June, 1900, all kinds of stock were being fattened upon green alfalfa. In addition to the alfalfa, Mr. Ray has a thriving orchard of peach trees just coming into thrifty bearing. The Santa Lucia systems are shown in the map, fig. 5.

BIG BEND.

The land along the Rio Grande in the Big Bend is very rich and will raise any crop that grows in Texas. Its yield is enormous, as many as 80 bushels of corn and 50 bushels of wheat being grown to the acre. Irrigation on a small scale is practiced extensively.

Candelaria ditch.—At Candelaria, a Mexican settlement on the Rio Grande about 45 miles from Shafter, there is an irrigation ditch 4 miles long, which was built by the Mexicans. It is fed by Coyote Creek, and irrigates about 200 acres. The Rio Grande is generally dry at this point during the irrigation season, but when it flows part of its waters are deflected into the Candelaria ditch.

Dawson system.—At Shafter Mr. G. S. Dawson has two tanks that are filled from a strong spring. Small ditches, or acequias, lead from the tanks and irrigate his farm, orchard, and garden. The land not in orchard or garden is sowed in wheat, which is cut green to serve for feed, and the land is then plowed and planted in corn and beans.

Del Rosa ditch.—The Rio Rosa ditch is 6 miles long, 6 feet wide,

and from 2 to 4 feet deep. It was built about 1880. A low dam of loose rock, 1 or 2 feet high, is constructed across the Rio Grande, and serves to irrigate about every other year 1,200 acres.

Palvo Irrigation Company ditch.—About 10 miles below Presidio the Palvo Irrigation Company has a ditch 5 miles long, 6 feet wide, and 6 feet deep. Water is obtained by means of a dam of loose rock, 500 feet long and from 2 to 4 feet high, which was constructed across the Rio Grande in 1877. Two miles above Presidio the Rio Concho of Mexico enters the Rio Grande, affording an abundant supply for this ditch. Above the mouth of the Rio Concho the flow of the Rio Grande is unreliable.

Mulato canal.—Opposite the Palvo canal, on the Mexican side, is the Mulato canal, in the State of Chihuahua. This canal shows what can be done by irrigation in the Big Bend. It is 6 miles long, 10 feet wide, 4 feet deep, and supports 1,000 persons. It is taken out of the Rio Grande a short distance below the Palvo dam, and reenters the river at the Mexican village of Mulato, below Palvo.

Ernst and Lindsey systems.—Near Boquillas, on the Rio Grande, in Brewster County, there are two small irrigation plants which take their water from Tornillo Creek, which is dry most of the year, but affords excellent opportunities for impounding. Mr. A. Ernst owns a ditch 900 feet long, 4 feet wide, and 3 feet deep, which was constructed in the early part of 1901, on the east side of the creek. The soil here is sandy and of good productive possibilities. Twenty acres, in corn, cotton, and beans, were irrigated this year (1902). The plant of D. E. Lindsey is on the west side of the creek. The ditch was constructed in 1898. It is 1,500 feet long, 3 feet wide, and 2 feet deep. The earth dam across the creek is 400 feet long and 6 feet high. Thirty acres, in beans and corn, are cultivated at this plant.

Ditches along Alamo and Leoncito creeks.—Two ditches have been taken out of Alamo Creek, in Brewster County. The first of these, taken out in 1880, is 2 miles long, 3 feet wide, and irrigates 250 acres of corn, beans, wheat, and sorghum. The water is deflected into the ditch by a dirt dam 40 feet long and 4 feet high. A ditch has also been taken from Leoncito Creek. Its length is one-fourth of a mile, its width 1 foot. It irrigates 3 acres of alfalfa. Two other small ditches, irrigating about 3 acres each, derive their water from small springs.

Pool system.—A few miles from Shafter, on the ranch of J. R. Pool, 5 acres, in vegetables and fruits, are irrigated. The water is derived from springs, and the peaches produced are of excellent quality and abundant quantity.

Hosier Brothers system.—The Hosier Brothers, near Dryden, have two small ditches, from which 24 acres are irrigated. The larger one is three-fourths of a mile long. It was built in 1898 and 1899, takes its water from a spring, and irrigates 19 acres in corn. The smaller

ditch was built in 1894, is one-fourth of a mile long, takes its water from Arocha Spring Creek, and irrigates 5 acres of sweet potatoes, melons, and vegetables.

Ditches in Jeff Davis County.—In Jeff Davis County, along Limbia Creek, several small gardens and farms, aggregating nearly 100 acres, are irrigated.

Templeton system.—Thirteen miles northwest of Alpine and 15 miles southeast of Fort Davis, in the county of Jeff Davis, there is an irrigated system on the Templeton ranch. Two natural springs from the side of a mountain supply the water to irrigate an 18-acre orchard containing about 2,000 fruit trees, consisting of apples, peaches, plums, pears, apricots, quince, and almond. The two springs irrigate separate pieces of ground. The one near the residence supplies water for domestic use, irrigates about 2 acres, and waters the domestic stock. In connection with this is a cement tank, having a capacity of 11,000 gallons, which is supplied by pipes that lead from the spring and fill it in about thirty-six hours. This amounts to about one-third the flow of the spring. The larger spring irrigates directly 15 acres without the intervention of a reservoir.

Two miles above this place is located a field of about 30 acres which is supplied by one or more springs. No ditches are used, but the forage crops, consisting of alfalfa, Johnson grass, and cane, are subirrigated, and when not used for pasture the field produces three or four crops each year.

PECOS VALLEY SYSTEMS.

Pecos River rises in the northeastern part of New Mexico and flows in a general southerly direction through the southeastern part of that Territory, crossing the western prolongation of Texas and finally entering the Rio Grande at about the lower third of the length of that stream. It is supplied to a considerable extent by water from large springs in the limestone rocks of the region, of which Roswell is now the principal town. These maintain the perennial flow of the river, the run-off from the catchment basin being irregular in character and diminishing at times to relatively small amounts.

Large irrigation works have been constructed in the vicinity of Roswell, which utilize the greater part of the summer flow of the river so that during the dry season of the year little water crosses the Texas line. Large storage reservoirs have been created both at Roswell and above Carlsbad. Between Carlsbad and the Texas State line there are several reenforcing springs. The water that flows in the stream is largely derived from the seepage of irrigated lands above, and is often heavily charged with alkaline salts. Irrigation canals have, however, been constructed along the valley in Texas, principally near the town of Pecos, at the crossing of the Texas and Pacific Railroad. The valley is fertile, and where properly irrigated large crops are produced.

MARGUERETTA CANAL.

The most important irrigation system along the river in Texas is the one about 50 miles from the New Mexico line known as the Margueretta canal system (see fig. 4). It was begun in 1887 by the Pioneer Canal Company, which afterwards consolidated with the Margueretta Canal Company, which now owns the whole system. Water is diverted by means of a brush dam, it being deemed impracticable to build a masonry structure in the sandy river bed. The dam is 250 feet long and 5 feet high. The head gate is shown in Pl. II, *A*. As shown in fig. 4, the canal is taken out of the west side of the river, runs in a southwesterly direction for a distance of 3 miles, crosses the river in a flume (shown in Pl. III), and then runs in a general easterly

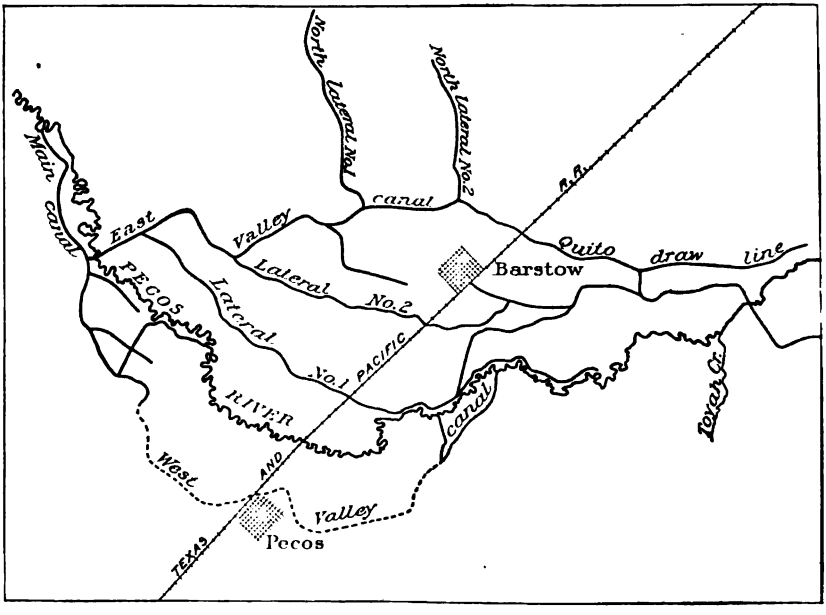

FIG. 4.—Map of Margueretta canal system.

direction for 12 miles. There is also a branch continuing down the west bank for a considerable distance, being the main part of the old Pioneer canal and now known as the West Valley canal, a view of which is shown in Pl. II, *B*. Thirty current-meter measurements during 1900 show that this ditch carries an average of 12 second-feet of water. The dimensions of the main ditch are: Top width, 30 feet; bottom width, 18 feet; depth of water, 4½ feet. There are three principal laterals, with bottom widths of 12, 6, and 8 feet, respectively. In Pl. IV, *A* and *B*, are shown a sluice gate and a measuring weir used on the canal.

The canal was first used in 1889, and the extent of land irrigated

A. HEADGATE OF MARGUERETTA CANAL.

B. ROCK CUT IN CURVE OF WEST VALLEY DITCH, MARGUERETTA CANAL.

MARGUERETTA FLUME ACROSS PECOS RIVER.

by it is steadily increasing. The total cost of the system was more than $150,000, and it is designed to cover about 40,000 acres, only 6,000 of which are, however, yet under cultivation. The water rights are sold at $10 an acre, a permanent right guaranteeing 25 miners' inches of water to the acre. The annual rental is $1 and $1.50 for each acre served with water. The principal crop is cotton, of which there are about 3,500 acres. The other crops cultivated are alfalfa, sugar beets, and all kinds of forage plants, fruits, and vegetables. Sugar beets tested in 1896 showed between 14 and 20 per cent of saccharine matter. Peaches, apples, and grapes do well. Cotton averages 500 pounds of lint to the acre. The annual rainfall is about 12 inches. Owing to the high elevation (2,700 feet) the seasons are much later than in most of the irrigated districts of the State.

The enterprise seems to have been conducted with energy and care, the canals and head gates are well planned and well built, and altogether the scene about Barstow, the center of the irrigated portion, has a general air of healthy growth and prosperity that is very pleasing to the eye after the many miles of desert scenery between there and El Paso. There are, however, a number of problems that must be solved before agriculture will be everywhere successful. Much of the land is impregnated with what is known as alkali. At first this does not prove troublesome, but after a few years of cultivation it may be brought to the surface by injudicious treatment, and the river water used in irrigation continually adds to the supply of this mineral matter. The only remedy so far applied is drainage, which is as important in its way as irrigation. The land is nearly level, and considerable care will be required to provide means by which the accumulated alkali can be washed from the soil.

One of the principal crops is alfalfa, which sells at $8 a ton on the cars at Pecos and $10 a ton retail. Alfalfa (*Medicago sativa*) will grow on almost any land, under almost any conditions, but satisfactory results can be expected only on a naturally deep, loose, porous soil, preferably deep sand, underlain with gravel, so that good drainage is assured.

PECOS RIVER IRRIGATION COMPANY.

About 28 miles below Pecos is the head gate of the canal of the Pecos River Irrigation Company, on the west side of the river, running in a general southeasterly direction for 12 miles. It is the oldest ditch on the river in Texas, having been built in 1875 and 1876. It was enlarged in 1889 and used again in 1890, but has never been entirely completed in its enlarged condition. It takes all its water by means of a brush-and-stone dam about 60 feet long and from 5 to 6 feet high. The total cost of the undertaking was about $35,000. It was designed to irrigate 20,000 acres, but only 100 acres were irri-

gated in 1901. The water supply was very short for several years, especially in 1892, 1893, 1894, and 1898, after the dam at Carlsbad, N. Mex., was completed. The flow has increased since then, but the river becomes quite low and the water bitter in March and April of each year. The soils and crops raised are similar to those at Pecos and at Barstow, but as at times only 15 second-feet of water are permitted to pass Pecos, the supply and quality are entirely inadequate to meet the demands.

GRAND FALLS.

The Grand Falls Irrigation and Improvement Company takes out a canal 4 miles below the head gates of the one last described, but on the opposite side of the river. It was begun in 1896, and 16 miles of it are finished. It is supplied by a brush-and-stone dam across the

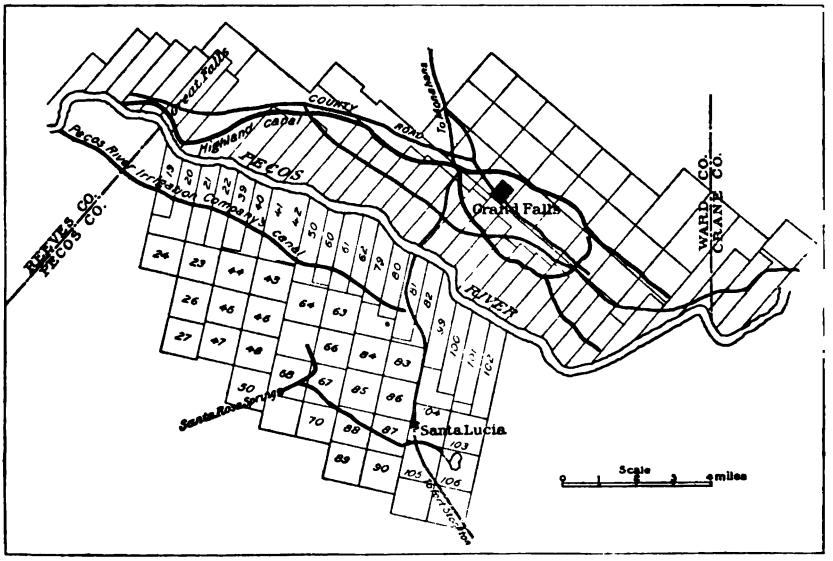

FIG. 5.—Map of Grand Falls and Santa Lucia irrigation systems.

river, 100 feet long and 7 feet high. The water rights are valued at $15 an acre; the annual assessment is $1.25 an acre. The company has completed an excellent system of canals in one of the most fertile valleys in Texas (see fig. 5), but the enterprise, like that of the Pecos River Irrigation Company, left two factors out of its calculations or gave them too little weight—i. e., the minimum flow of the river and the amount of alkali it carries at low stages. Both factors prove almost conclusively that only alfalfa can be raised on either side of the river near Grand Falls. The brackish condition of the water will affect the young alfalfa, but after it gets stronger it can stand it and water can be applied at will. By judicious management a small amount of alfalfa can be produced in paying quantities, notwithstanding the alkali in the water. The Pecos and Grand Falls systems have fallen far below expectations.

A. SLUICE GATE USED ON MARGUERETTA CANAL.

B. MEASURING WEIR ADOPTED BY PIONEER CANAL COMPANY.

EDWARDS PLATEAU SYSTEMS.

The Edwards Plateau comprises the region bounded by Colorado River on the north and northeast, by the International and Great Northern and the Southern Pacific railroads, and by Pecos River. The systems treated under this section are those included in the plateau and its foothills, including, in whole or in part, the systems in the counties of Valverde, Kinney, Edwards, Kimble, Menard, San Saba, and Kerr. From the foothills of the plateau numerous large springs gush forth from the limestone rocks, and many of these have been utilized for water-power and irrigation purposes. Springs occur at Lampasas (the Hancock and Hanna springs; volume, 15 second-feet); at Walton's ranch, near Bartlett; at Mormon Springs (volume, 10 second-feet), on the banks of the Colorado, 1 mile above the Austin dam; at Barton Springs, 1½ miles southwest of Austin (with a volume varying from 18 to 70 second-feet, the average being 30 second-feet); at San Marcos, forming San Marcos River (minimum volume, 70 second-feet); at New Braunfels (minimum volume, 300 second-feet), forming Comal River; at San Antonio, with a volume varying from 9 to 125 second-feet; at Uvalde, with a volume varying from 0 to 15 second-feet; at Brackettville (the Las Moras, with a minimum volume of 21 second-feet); at Del Rio, in the San Felipe Springs and Creek, with a minimum volume of 60 second-feet; along Upper Nueces River, in the Edwards Plateau; the Kickapoo Spring, in Tom Green County, etc. The systems treated here are those at Del Rio, including Cienagas Creek; those along Mud and Los Moras creeks; those along the Upper Nueces; those near Menardville; and those in Kerr, Kimble, and Edwards counties.

DEL RIO.

At Del Rio is one of the most effective and successful irrigation systems in Texas. A map of it is shown in fig. 6. The water is supplied from San Felipe Creek, a short stream formed by four large springs, about 1 mile east of the town, within a fourth of a mile of one another. In the 4½ miles from the springs to the Rio Grande the fall of the stream is 62 feet, thus furnishing an excellent water power for manufacturing purposes. Four ditches have been taken out, two of them for irrigation. They are supplied with water by means of two permanent masonry dams 65 and 150 feet in length, respectively, and each 8 feet high. The smaller dam, shown in Pl. V, *B*, is nearest the springs, and is the starting point of the San Felipe ditch, shown in Pl. V, *A*.

The first ditch was started in 1868 by James H. Taylor and others. The company purchased about 6,000 acres of land, including Cienagas and San Felipe creeks. In 1869 several hundred acres were irrigated from this ditch. The second ditch was taken out in 1869, with a capacity to serve 1,600 acres. The third was started in 1873; 2½ miles were built in 1874, and it was widened and completed in 1875. The

ditches are now owned by the San Felipe Agricultural, Mechanical, and Irrigation Company, the shares in which are held by owners of the land commanded by the ditches. The total cost of the ditches was about $25,000, and the annual cost of maintaining them is about 50 cents per acre per annum. The main ditches measure about 4½ miles in length and are 10 feet wide at the top, have perpendicular sides, and carry about 2 feet of water. The laterals are four in number, with an average width of 4 feet and a total length of 24½ miles, making the total length of the ditches 30 miles. The area irrigated is 3,600 acres (in meadow, cotton, corn, gardens, orchards,

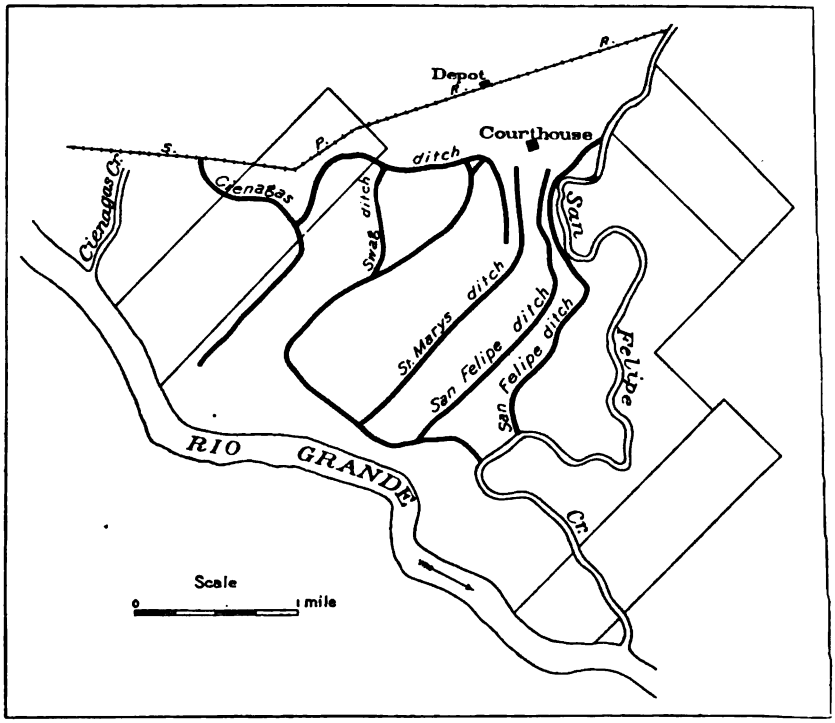

FIG. 6.—Map of Del Rio irrigation system.

and vineyards), although 5,000 acres can be irrigated. All kinds of fruits and vegetables are grown in profusion. On June 15 of this year (1902) melons, plums, and apples were ripe. The impression made on the traveler who comes from the droughty and sun-scorched plains is not soon forgotten. This cultivated tract has been so isolated from the rest of the agricultural world that none of the diseases which so reduce the profits of the grape and fruit grower elsewhere have yet been introduced. Grapes produce from 6,000 to 10,000 pounds to the acre, and are mostly made into wine, the yield of which is from 10 to 16 barrels to the acre.

A. DAM SUPPLYING SAN FELIPE DITCH AT DEL RIO.

B. DAM SUPPLYING MADRE DITCH AT DEL RIO.

CIENAGAS CREEK.

Cienagas Creek rises in the Cienagas Spring, in section 179, about 3 miles west of Del Rio. A dam 690 feet long and 25 feet high was constructed across the creek in 1875. This deflected the water into a ditch that skirted the foothills to the west, and then turned toward the east, after crossing the tracks of the Southern Pacific Railroad, as shown in fig. 7. The ditch is 3½ miles long, 6 feet wide, and 4 feet deep. The flow is sufficient to irrigate 800 acres. The principal crop is Johnson grass, which is raised for hay. The year 1900 was so wet

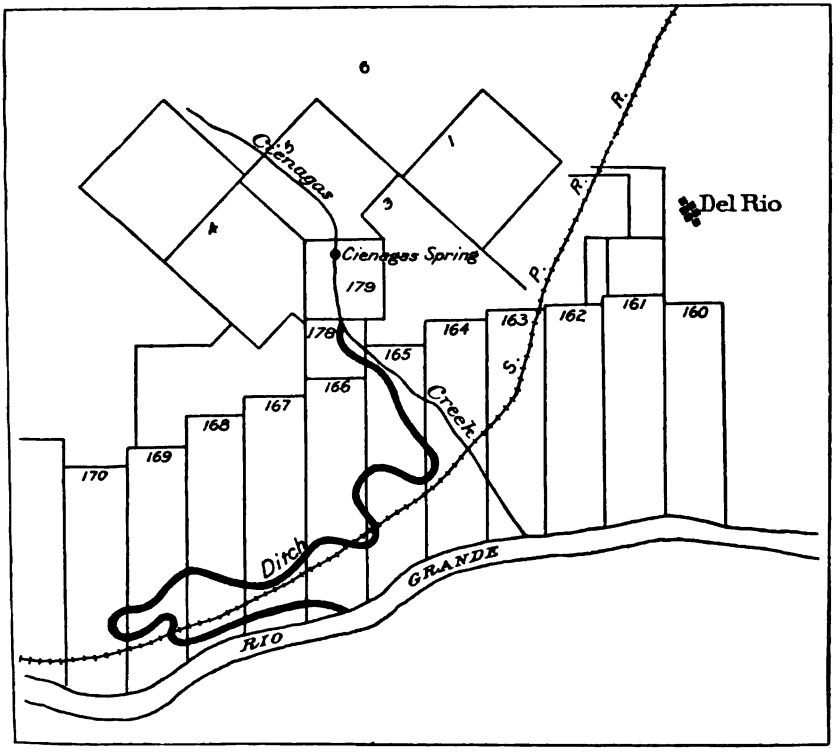

FIG. 7.—Map of Cienagas Creek irrigation system.

all over Texas that no irrigation was needed to produce an excellent hay crop. The hay farms lie along the Southern Pacific Railroad, between it and the Rio Grande. The yield in 1900 was 5 tons to the acre.

MUD CREEK.

Mud Creek, which is about halfway between Las Moras and San Felipe creeks, has had a varied history. Several attempts have been made to utilize its waters for irrigation purposes. The creek rises in large springs about 7 miles north of the crossing of the Southern

Pacific Railroad. At one time there was a dam across the stream just below the springs which backed the water over the springs, and it was claimed that this was one of the causes of the stream going dry. The dam was finally blown out, but the creek did not regain its former flow until the spring of 1900. It was practically dry from 1893

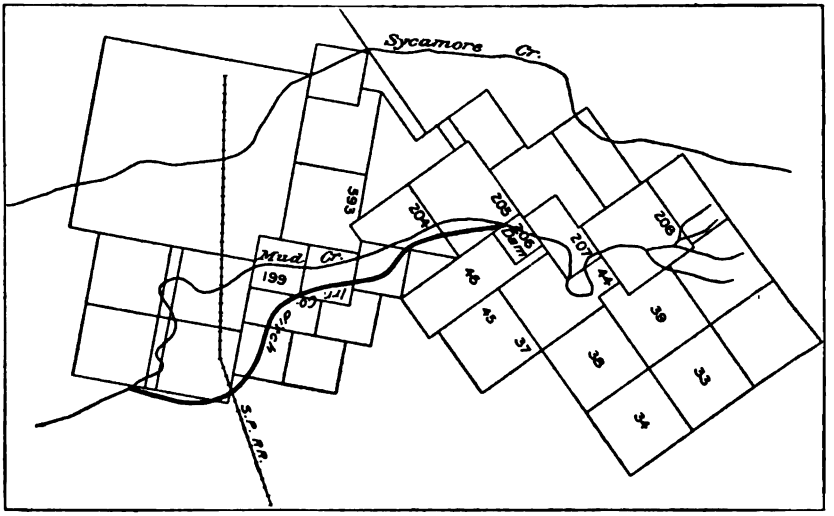

FIG. 8.—Map of Mud Creek irrigation system

to 1899. Its revival was simultaneous with the revival of the Leona and San Antonio rivers. A ditch, shown in fig. 8, is taken out of the creek on its west side 3 miles above the railroad, and in 1900 about 400 acres were irrigated from it.

LAS MORAS CREEK.

Las Moras Creek rises in large springs near Brackett. The flow in 1895 was 21 second-feet, and in 1900 it was 51 second-feet. The waters of the creek are used for irrigating farms and gardens within 10 miles of Brackett.

Government ditch.—The ditch nearest to Brackett, shown in fig. 9, is the property of the Government, being used by the Seminole Negro Indians, who live on the Fort Clark Reservation. It is on the west side of the creek, and is about 1 mile long, 5 feet wide, and 1 foot deep.

Indelkofer-Gilder ditch.—The Indelkofer-Gilder ditch, also on the west side of the creek, is taken out 1 mile below the intake of the Seminole ditch. Its dimensions are: Length, 600 feet; width, 4 feet, and depth, 1 foot; 15 acres are irrigated from it.

McGovern ditch.—The McGovern ditch, from which 8 acres are irrigated, is taken out on the east side a short distance above the intake of the Indelkofer-Gilder ditch. Its length is 600 yards, depth 1 foot, and width 5 feet.

Smith and Stratton ditches.—About 6 miles below Brackett two ditches—the Smith and the Stratton—are taken out, one on the west and the other on the east side of the creek. The Smith ditch is 600 feet long, 4 feet wide, and 1 foot deep, and irrigates from 6 to 10 acres of garden. The Stratton ditch is 3 miles long, 8 feet wide, and 1 foot deep, and irrigates a hay farm of 250 acres below the Southern Pacific Railroad. In March, 1902, through litigation, Judge Stratton lost part control of the ditch which bears his name, and he therefore abandoned it and installed a pumping plant on the Las Moras. This

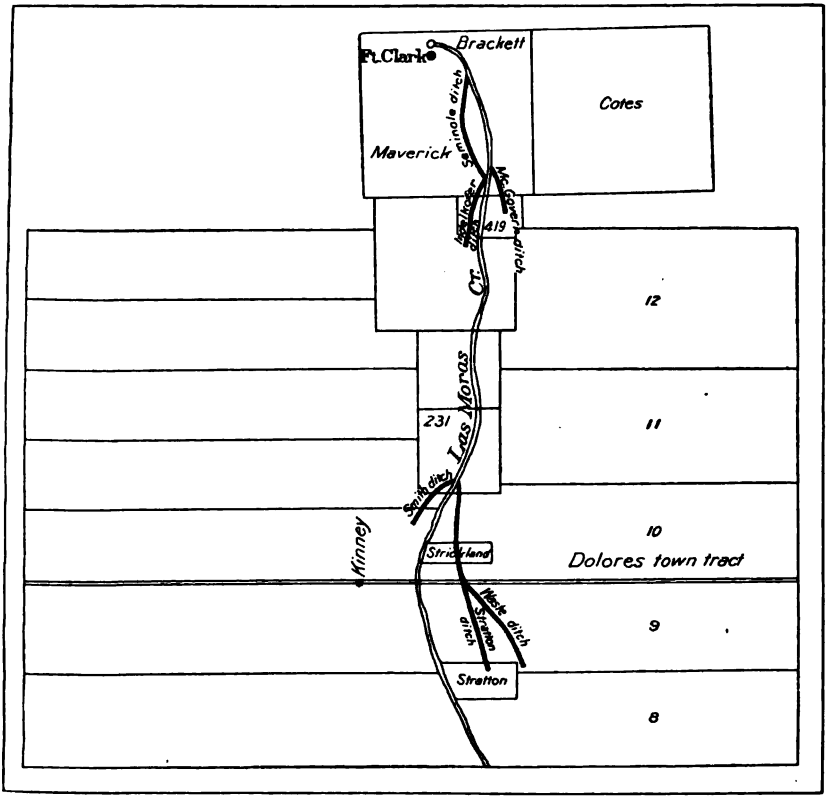

FIG. 9.—Map of Las Moras Creek irrigation systems.

plant can readily be seen from the Southern Pacific trains as they near the bridge on the Las Moras. The machinery consists of a 40-horsepower Ames steam engine, which operates an 8-inch Gould centrifugal pump against a lift which varies from 17 to 20 feet. Eagle Pass coal is used for fuel, and it requires 2,500 pounds for a complete day's run. The capacity of the plant is 4,750 minute-gallons, and in very dry seasons it exhausts the twenty-four hours' impounded flow of the Las Moras in two and a half hours. A small dam is constructed across the stream, which forms a reservoir in the channel, and is allowed

to impound the water in irrigation season for twenty-four hours. The water is delivered into a flume 15 by 30 inches, 2,000 feet long, which carries it to the highest point of the land. Johnson grass is the main crop, and three crops are made each season, averaging 2 tons to the acre, which in August, 1902, was selling for $14 a ton. This is somewhat higher than usual, but it never sold for less than $11 a ton.

SAN SABA VALLEY.

The San Saba River rises in springs 1½ and 3 miles above Fort McKavett. The total flow of these at the crossing a mile below town was found on August 14, 1902, to be 13 second-feet. There are in all eleven different irrigation systems in Menard County that take their water from the river or the springs that feed it. These are the Ball, Perry, Byers, Dickinson, Striegler, Spitgarber, Coghlan, Noyes, Sieker, Kitchen, and Vanderstücken.

Ball system.—The plant of Tom Ball is north of Fort McKavett and takes its water from the San Saba by means of a pump run by a 20-horsepower steam engine. It is intended to irrigate 50 acres.

Perry system.—Seven miles east of Fort McKavett, on the south side of the river, W. J. Perry irrigates 30 acres from the Sheen spring, which comes out of the foothills in a flow of 1 second-foot. This system has been in operation a long time, and double the acreage could be brought under irrigation.

Spitgarber and Coghlan systems.—At the Spitgarber ranch, 6 miles above Menardville, there is a bold spring flowing out of the foothills. A ditch taps this spring and irrigates 20 acres. One mile above the Spitgarber ranch, on the Coghlan ranch, occurs another spring. A ditch taps the outflow of this spring and irrigates 40 acres.

Byers systems.—Twelve miles above Menardville is Byers's vineyard. The dam is almost as unique in construction as that of Captain Sieker. Into the rock bottom holes were drilled across the river and small iron posts were inserted. An iron brace was attached to each post, the other end of the brace fitting a hole drilled into the rock bottom. A plank was attached to the upper side of each post and adjusted to fit the configuration of the river bed. On the top of this bottom plank another plank was placed and attached to the posts. The race was blasted out of the solid rock on the north side of the river. Two stone piers were built up to form supports for the axis of the undershot water wheel. To the wheel are attached buckets which carry a certain amount of water to the level above, and in addition the wheel is made to operate a pump which reinforces the flow from the buckets. This plant irrigates a vineyard, the fruit of which is converted into wine. A half mile below this vineyard is the plant of the younger Byers, which is similar to that just described.

Clear Creek systems.—Clear Creek, 3 miles long, issues from the mountains in a bold spring, which had a capacity on August 14, 1902,

when measured, of 21 second-feet. The owner, W. J. Wilkinson, a settler of forty years' residence, states that during the summer the flow is larger than it is during the winter. The waters are used by two small irrigation systems, the Wilkinson and the Striegler. A small rock dam at the head deflects part of the waters into the two ditches of the Wilkinson system, from which 12 acres are irrigated on each side of the creek. Near the mouth of the creek O. Striegler, by means of a rock dam 8 feet high and about 50 feet in total length, that deflects the water into a ditch on the left side of the creek, irrigates 18 acres in corn, cotton, oats, melons, etc. It is well to remember that the capacity of this creek was exactly three-fourths of that of the Noyes ditch near the courthouse in Menardville on the same day.

Old Mission ditch.—The San Saba mission was established at what is now known as old Fort San Saba in 1734, and it was from this the river took its name. The Franciscan fathers who established the mission constructed a system of irrigation the remains of which can

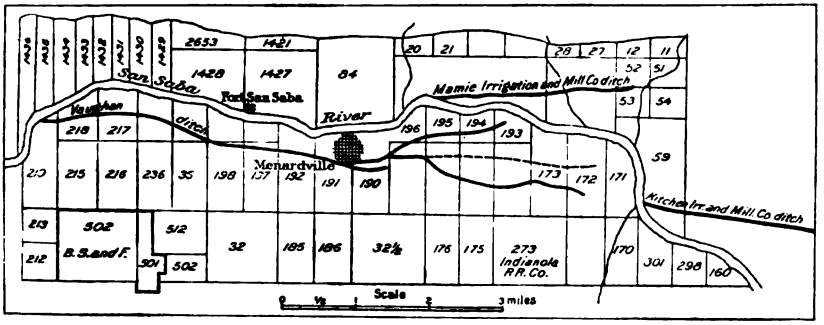

FIG. 10.—Map of Menardville irrigation systems.

be easily traced to-day. The dam was a short distance above the mission and the ditch was taken out on the south side of the river and skirted the hills one-half mile above Menardville.

There are three systems near Menardville—the Vaughan, the Sieker, and the Kitchen. (See fig. 10.)

Noyes ditch.—The Noyes ditch is nearly 10 miles long. The dam is built across San Saba River about 4 miles above Menardville, and the water returns to the river 5 miles below that town. The charter was obtained by the Vaughan Agricultural and Improvement Company in 1874, and the ditch was built soon after. It is claimed that this company put $12,000 into the work. This was an excessive cost, extra expense being incurred by the refusal of right of way in one instance, forcing the company to make a cut 16 feet deep and several hundred feet long. Further, the methods employed were rude and costly. Wheelbarrows were used to move the dirt, and in the cut the earth was thrown on staging and passed from man to man. There are 97 shares of stock, valued at $180 each. One year $1,200

was spent in improvements and another year $1,000, but the ditch pays all running expenses, cost of improvements, and 10 per cent on the shares at the foregoing valuation.

After construction the grade of the ditch was found to be irregular and unsuitable, so work has been done each year—cutting and filling—to reduce the slope above the Las Moras flume to a nearly uniform grade of 30 inches to the mile. At the flume there is a fall of 14 inches in 128 feet. At the point of the mountain, where the ditch curves with the hill and runs through rock, it is lessened in size and has a much steeper grade. The grade of 30 inches to the mile was established experimentally and satisfies as nearly as possible the necessity of avoiding silting on the one hand and erosion on the other. The ditch runs through coarse gravel part of the way, and there is a heavy loss from percolation. The straightening of the ditch, the reduction of the grade, and the tightening of the dam have given an available flow of water sufficient to irrigate 2,000 acres of land.

The dam is of rough limestone quarried at the spot, averaging, where seen on the front, 2 feet by 3 feet by 10 inches, and laid in courses without cement. The blocks are tied by bolts fastened to a log under the dam, passing up through the dam, and at the top are fastened by taps to cross-ties lying along the upper surface. The dam is slightly concave, and is about 200 feet long and 5½ feet high at the center of the front, with an irregular batter. It is 13½ feet wide on top at the center. It rests partly on rock and partly on gravel, and is backed with earth on a slope of nearly 2 to 1.

The water stands within a few inches of the top of the dam and overflows at every rise in the river. Judging from the high-water marks there are 10 or 12 feet of water passing over it at times. Below the dam is a pile of loose bowlders which holds the leakage through the dam and forms a water cushion to receive the fall. At every high rise the dirt is washed from the back of the dam, and when the water subsides it is at once replaced by dirt scraped from the north side of the river. The dam backs the water about 500 yards, the deepest hole being about 15 feet. The water is taken out on the south side, 100 or more yards above the dam, and is carried in a cut to the sluice gate a short distance below the dam.

A section of the ditch made a few hundred yards below the sluice gate gave the following dimensions: Top width, 15.2 feet; bottom width, 8 feet; depth, 2.7 feet; wetted perimeter, 16.5 feet; area, 29.83 square feet; maximum surface velocity, 2.17 feet per second, and mean velocity, 1.54 feet per second. The velocity was measured for 100 feet above and below the section, where there was not a very great difference in the dimensions of the ditch. The fall of the surface was found to be 0.1 foot in 195, or 1 foot in 1,950, or 2.7 feet in a mile. This, with a coefficient of $n=0.03$, would give a velocity of 1.57 feet per second, which is very near the observed velocity of flow, and

gives a discharge of 46 cubic feet per second, or 2,300 inches, estimating 50 inches to 1 foot.

The flow of the main ditch was measured by current meter in August, 1902, at the bridge near the Methodist Church and it was found to be 28 second-feet. Two small ditches, one on the north side of Main street and the other skirting the foothills of the south, taken out above the bridge referred to, were carrying one-third and 1 second-foot, respectively.

As to the amount of water required to the acre, one man who irrigates 40 acres of land uses 40 inches of water and occasionally needs a little more. On another farm they use 15 inches of water on 12 acres of garden truck. On the upper part of the ditch above the town the water is measured and distributed by the inch; that is, if a man wants 20 inches of water the gate opening on his ditch is set for a 20-inch flow and remains in that position throughout the season. From the town down they use the water in rotation, because, owing to a mistake in laying out the distributaries, the use of water above interferes with the flow below. So they alternate every seven days, the residents above using all the water that reaches them during that period, the lower owner having all the water during the next seven days. One-half mile below the town the Waller lateral runs off to the left toward the river bend. At present (1902) it is the custom to let those on the Waller have the whole flow one week and those on the main ditch the next, etc.

Assuming the acreage irrigated to be 2,000 acres, we have from our calculated flow a little more than 1 inch to the acre, which is the allowance in actual use, and a duty of 44 acres per cubic foot per second of flow for the water entering the main ditch. These measurements were made at but one point, and can be considered only approximate for the whole ditch. For accuracy they should be repeated at a number of points and proper allowance be made for percolation and leakage. In general, the estimate is that three waterings of 4 inches will make a crop.

Sieker system.—One mile below Menardville is the dam of Capt. L. P. Sieker. It is of peculiar construction, as shown in fig. 11. In a line across the river piles 6 feet apart were driven into the bed of the river with a pile driver, being left 5 feet above the river bottom. Parallel to this row and 6 feet from it another row of piles was driven in such a way that the piles of the lower row were immediately below those of the upper row. The piles were thus located at the corners of 6-foot squares. The piles of the lower row projected only 3 feet above the bed of the river. Sheathing boards 2 inches thick were spiked on the upper side of the upper row of piles, while logs were laid against the upper side of the lower row of piles and were wired to them. The inclosure between the sheathing and the logs was filled with loose stone. This added weight and increased the stability

already obtained by sinking the piles. To prevent leakage cedar tops were piled above the dam and were tramped into the soil and against the dam. On top of the cedar boughs earth was filled to within a short distance of the top. This method of constructing a dam has proved very successful. The dam is 380 feet long, 5 feet high, and 6 feet wide.

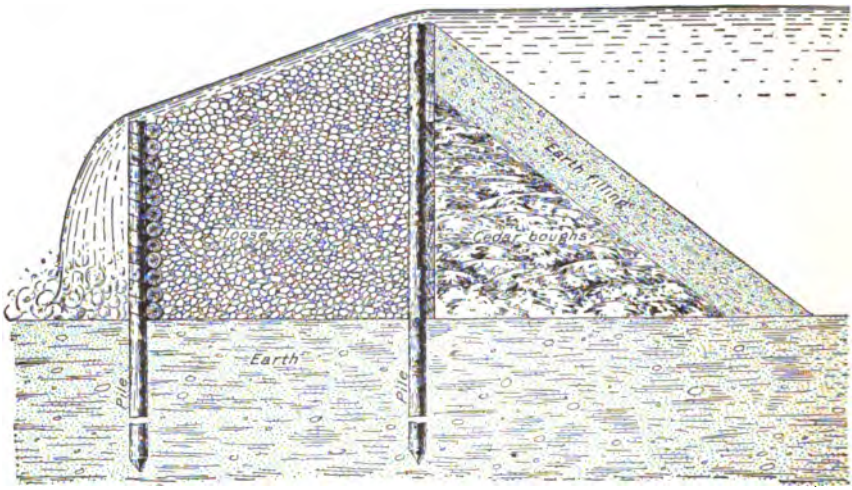

FIG. 11.—Cross section of Sieker's dam on San Saba River.

From the lake thus formed leads the ditch known as the Mamie ditch, built in 1894. It was chartered for a length of 4 miles, but only 1¾ miles have been constructed. It is 6 feet wide and 2 feet deep. At one place it is forced to within 30 feet of the river, on account of the foothills crowding up to the river bank. The cut at this place was 18 feet deep and the bottom of the ditch 9 feet above

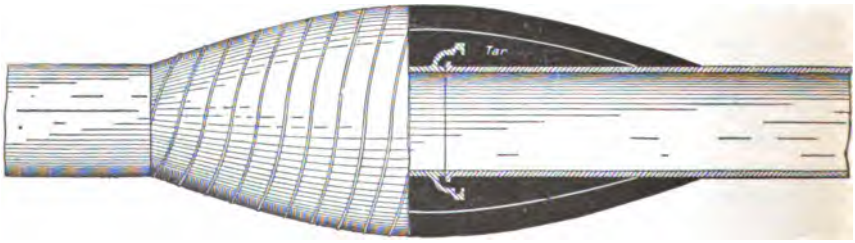

FIG. 12.—Flexible pipe joint used on the Mamie ditch.

the ordinary water level of the river. One hundred and seventy-five acres are irrigated from the ditch, but it has a capacity of 200 acres. The chief crops are cotton and corn. Cotton averages from 1½ to 2 bales and costs $1.25 a bale for transportation to the railroad. Corn brings from 15 to 20 cents more a bushel than at the markets on the railroad. Sweet potatoes average 250 bushels to the acre.

The ditch crosses four streams, Millers Branch, Temple Branch,

Temple Field Creek, and Scalp Creek. At first the old form of wooden flume was used across these creeks and branches, the channels being 4 feet wide and 2 feet deep, but the excessive heat of summer caused constant leaks in the flumes, and they were finally abandoned as water carriers. The sides were taken off and the floors were left as supports for the pipe lines which were substituted to carry the water across the creeks. To counteract the expansion due to the heat a flexible joint, shown in fig. 12, was designed to connect the sections of the pipe. After the ends were brought together several inches of the pipe near the joint was heavily coated with North Carolina tar, heavy canvas was wrapped around the joint, the whole was again tarred, and the canvas was securely strapped to the pipes by wires twisted around the joint. A bulkhead was constructed across the ditch on each side of the creeks and the pipes were built into the bulkheads. At Millers Branch the flume pipe is 90 feet long, 18 inches in diameter, and has a fall of 14 inches; at Temple Branch the length of the pipe is 50 feet, its diameter 15 inches, and the fall 9 inches; the Temple Field flume pipe is 125 feet long and 12 inches in diameter, and the fall is 18 inches; at Scalp Creek the length of the pipe is 180 feet, its diameter 13 inches, and the fall 18 inches. All of these flexible joints and pipe flumes have proved eminently satisfactory.

Kitchen ditch.—This ditch is taken out 6½ miles below Menardville and 5½ miles below the Sieker or Mamie dam. The dam is of brush, rock, and dirt, about 75 feet long and 7 feet high. The ditch leading from the lake formed by the dam is 4½ miles long, 6 feet wide, and 2 feet deep. Three hundred acres were irrigated from it in 1902.

Vanderstücken system.—Twelve miles east of Menardville, on San Saba River, is a pumping plant owned by Emile Vanderstücken, consisting of a 28-horsepower steam engine operating by a belt a Van Wie centrifugal pump having a capacity of 5,000 gallons a minute, or 11 second-feet, with a lift of 31 feet. The total cost of the plant was $1,500. No reservoir is used, the water being carried in a flume to the highest point on the land and distributed by ditches. The flume runs along a ridge for 150 feet and then branches.

Sloan system.—At Sloan, San Saba County, there is a series of perennial springs that gush forth from the foothills near San Saba River. Originally the water ran down to the low grounds and formed a pond, but about 1870 a ditch was constructed along the foothills to the river, which took the water away from the pond, and it soon dried up. A stone dam 200 feet long and 4 feet high was built to deflect the water into the ditch. The ditch shown in fig. 13 is 1 mile long, 5 feet wide, and 1 foot deep. The former pond is now an irrigated farm, through which runs a long sag. To convey the water across this sag a rock race and a pine and cypress flume are used. The soil is a rich, black loam, slightly sandy. The crops raised are corn, cotton, ribbon cane,

and sweet potatoes. The yield per acre is generally from 40 to 60 bushels of corn, from 1 to 2 bales of cotton, about 290 gallons of molasses, and from 150 to 300 bushels of potatoes. The ditch is owned by Mr. J. A. Sloan & Sons, and in 1902 it irrigated 186 acres.

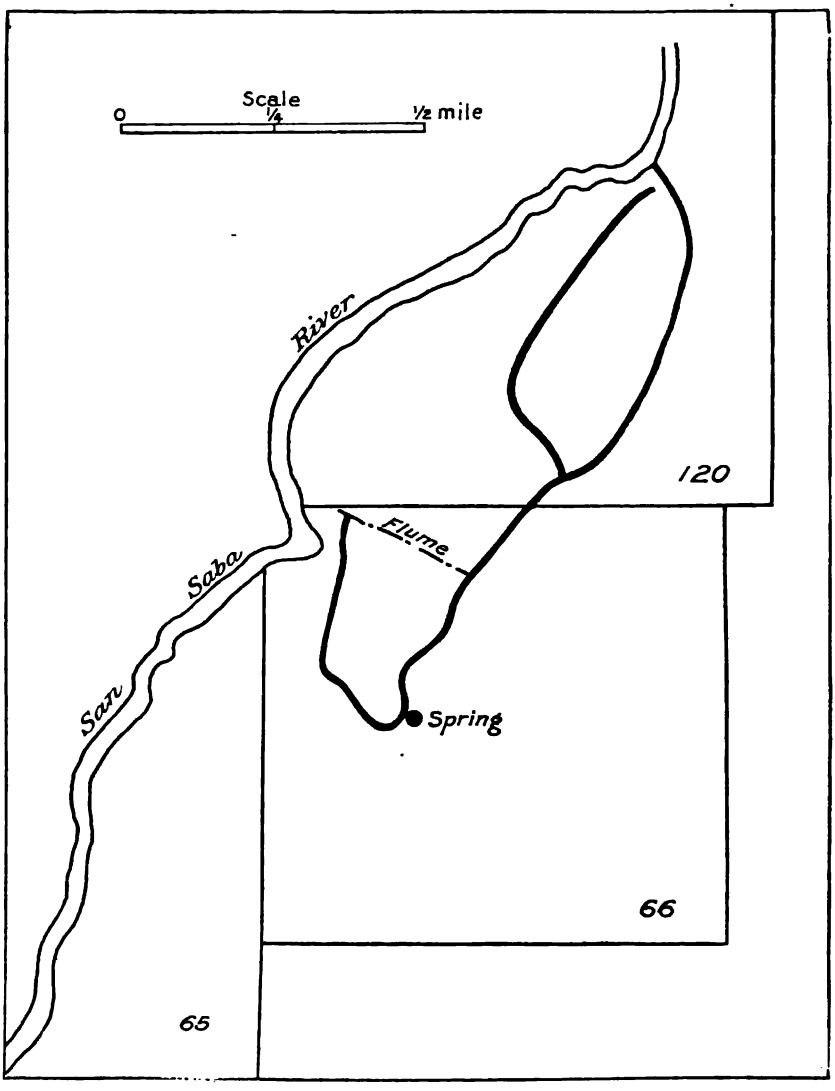

FIG. 13.—Map of Sloan irrigation system.

Doran system.—Seventeen miles west of the town of San Saba is the irrigation plant of W. R. Doran. The water is drawn from the river through a ditch 600 feet long into a pond from which it is pumped into the flume. A 16-horsepower engine runs a centrifugal pump against a lift of 28 feet, delivering 2 cubic feet per sec-

ond. One hundred acres (in cotton, millet, cane, and corn) are to be irrigated.

West & Burnet system.—Ten miles northwest of San Saba West & Burnet have constructed an impounding reservoir of an estimated capacity of 20,000,000 gallons, by making a dam across a drainway. The dam is 705 feet long, 14 feet high, and cost nearly $1,000. The ordinary crops will be irrigated and the number of acres the canal will serve will be determined by trial.

King system.—Probably the oldest irrigation plant in the San Saba country is that of the King Sisters (Larkin King, manager), just above Sloan, on the south side of the river. There are two springs, known as the Fleming Springs, that issue from the foothills of the mountains and supply the King farm with sufficient water to irrigate 40 acres.

Ellis system.—Twelve miles above San Saba, on the south side of the river, Robert Ellis operates a pump irrigation plant, which was first erected late in the season of 1902. A stationary tubular 25-horsepower boiler furnishes steam to a 20-horsepower engine, which drives a 6-inch Rumsey pump against a lift of 25 feet. The water is pumped out of a walled-in well 6 feet in diameter and 19 feet deep from top of curbing, the well being supplied from the San Saba River by a 15-inch wooden pipe, constructed of leveled 2 by 4 pine lumber. The water is pumped into a canal that conveys it to the fields one-fourth mile from the pump. Ordinary crops of corn, cotton, etc., are irrigated.

Hawkins system.—Eight miles above San Saba, on the farm of Mrs. M. E. Cook, Thomas Hawkins has equipped a pumping plant by a 12-horsepower charter gasoline engine, which runs a 4-inch vertical Van Wie centrifugal pump against a lift of 33 feet. The plant cost $825, and with it, by the use of $4 worth of oil, 6 acres can be irrigated by the furrow system each day. By this plant 40 to 50 acres can be irrigated each season.

Proposed canal system.—Many surveys have been made with the view of putting in an irrigation system on a large scale in the San Saba Valley. Seventeen miles above the town of San Saba, at the Narrows, the river issues from the canyons which it has traversed for a distance of 60 miles, from a point about 12 miles below Menardville. From the Narrows to the junction of the San Saba and Colorado a fertile valley on each side of the San Saba River could easily be brought under irrigation. The flow of the San Saba at the Narrows, as determined by two measurements in June, 1902, by the writer, at a time when no rain of importance had fallen in its watershed for two years previous, was found to be 24.5 second-feet. To irrigate the 42,000 acres in the valley below, a system of storage reservoirs could easily be constructed by putting in dams across the river at the Narrows and near the mouth of Brady Creek. The deflecting dam at the Narrows would be about 550 feet long and 60 feet high to fill the north valley canal, which would bring under

ditch all of the north valley between Doran's ranch and the Colorado. Two distinct surveys have been made by independent parties with the view of putting in a complete irrigation system in this valley. The soil is rich, and the possibility of irrigating the lands in the valley by storing up the flood waters in the deep canyons offers easy construction for the prospectors. Between the deflecting dam and Menardville there would be no adverse interest to complicate the situation, as there are no farming lands in this section of the river to be covered.

Systems east of San Saba.—Just east of San Saba there is a large tract of land extending from the mill creek that skirts the town to the foothills 3 miles east. This land could be irrigated easily, and offers an inviting field. From the lake formed by the dam across the creek a stone race leads out into a ditch that commands several hundred acres. The ditch is 2 miles long and is well built, as is shown by the substantial flume about one-fourth of a mile from the dam, which was used to carry the water across a sag. This ditch has not been utilized for two or three years, but it is reported that it will be brought into use again for the season of 1902. Near the foothills east of San Saba an effective spring, known as the Barnet Spring, furnishes sufficient water to irrigate the lands of Hambert Brothers and those of Mrs. Farrar. The ditch is a small surface trench, and could be rendered much more effective by repairs.

Maxwell system.—Twelve miles southeast of San Saba, on Rough Creek, Z. T. Maxwell has an irrigated farm of 40 acres, the water for which is supplied by perennial springs on the mountains. The water is conveyed from the springs by a ditch 1,500 feet long, which is tapped by three side ditches. The main ditch has a fall of 1 foot in every 300, while the side ditches have a fall of 1 foot in every 600. The soil is partly black loam and partly chalky and sandy. The farm has been in operation since 1880, and is one of the most successful in Texas. The crop in 1901 was distributed as follows: Twenty-one acres of onions, 2 acres of cabbages, 2 acres of tomatoes, 10 acres of millet, 5 acres of cane, and the remainder in corn, wheat, etc. A second crop is raised on the small-grain and the onion land. In 1901 the onion land yielded 180 bushels to the acre and a second crop of 50 bushels of peas to the acre.

Baker system.—Near Sloan post-office, on Richland Creek, a tributary of San Saba River, about 30 miles northwest of the town of San Saba, George Baker has a system of ditches from which he irrigates 150 acres, the principal crop being cotton. The water is taken from the Richland Spring by a cement and stone dam 25 feet long and 5 feet high. There are 2 miles of ditches on both sides of the creek, the width and depth of which are 4 feet and 2 feet, respectively. The plant was inaugurated in 1870, and the yield from the black and waxy valleys on each side of the creek is from 1½ to 2 bales of cotton to the acre.

UPPER NUECES.

There are several small irrigation plants in Edwards and Uvalde counties, on the prongs of Nueces and Frio rivers, in the vicinity of Leakey, Barksdale, Vance, Riofrio, Montell, and Laguna. The following persons have irrigation plants: Tom Woods and M. Clymer, near Rock Springs; W. B. Patterson and H. Elms, near Leakey; W. D. Hutcheson, O. A. V. Burr, John Nelson, M. Red, J. W. Sparks, W. F. Woodward, S. W. McLaughlin, Mrs. W. A. Connell, W. A. Shockley, J. K. Lippard, B. F. Casey, J. H. Woods, and E. M. Jones, near Barksdale; Z. H. Pannell and A. R. Barker, near Vance; W. T. Patterson, near Riofrio; J. H. Etheridge, at Montell, and William Landrum, at Laguna.

Woods system.—The Tom Woods plant is a small one on the Pulliam Prong of Nueces River. It was built in 1883. The dam, which is 150 feet long and 1½ feet high, deflects the water into the ditch. It is made of logs, rock, and dirt. The ditch is 600 yards long, 2½ feet wide, and 1 foot deep. The soil is black alluvial along the banks of the stream, and 8 acres are irrigated and planted in corn, potatoes, cane, and Johnson grass. The yields per acre are as follows: Thirty-three bushels of corn, 200 bushels of potatoes, 2 tons of cane, and from 3 to 4 tons of Johnson grass. About 1 acre is sublet to another party for a garden.

Clymer system.—The plant of M. Clymer was constructed in 1897, and consists of a ditch 1,300 feet long, 2 feet wide, and about 1 foot deep. It takes its water direct, without the aid of a dam, from Hackberry Creek, a tributary of the East Prong of Nueces River. The soil is a black loam, 4 acres of which are irrigated for garden truck.

Hutcheson system.—W. D. Hutcheson, near Barksdale, has two ditches, both of which take their water from the South Prong of Campswood Creek, a tributary of Nueces River. The first ditch was taken out in 1889, on the east side of the creek. It is 500 yards long, 2 feet wide, and about 1 foot deep. It takes its water from the creek without the aid of a dam. The second ditch was built in 1893, on the west side of the creek. It is 400 yards long and of the same general dimensions as the first ditch. The water is deflected into it by a rock-and-earth dam 20 feet long and 3 feet high. The first ditch irrigates 7 acres and the latter 13 acres. The soil is a rich, black loam, and readily produces 40 bushels of corn or 1 bale of cotton to the acre.

Nelson system.—John Nelson's plant was inaugurated about ten years ago. It is near the post-office of Barksdale, on the South Prong of Campswood Creek. The dam is of logs, stones, and earth, is 30 feet long and 4 feet high, and deflects the water into the ditch. The latter is taken out on the left bank, is 600 yards long, 25 feet wide, and about 1 foot deep, and irrigates 150 acres in corn, potatoes, and cane, yielding 40 bushels of corn, 280 bushels of potatoes, and 5 tons of cane to the acre.

Red system.—The ditch of M. Red is on the South Prong of Campswood Creek, near the Barksdale post-office. It is 625 yards long, 2½ feet wide, and of an average depth of 1 foot. It was constructed in 1890, and takes the water from the stream by means of a log, stone, and dirt dam 18 feet long and 2½ feet high. Twenty-three acres of black, porous limestone soil, in corn, potatoes, cane, and vegetables, are irrigated. The yield per acre is 40 bushels of corn, 225 bushels of sweet potatoes, and 5 tons of cane.

Sparks system.—The ditch of J. W. Sparks is taken out just below that of M. Red, but on the opposite side of the creek. It is 2,100 feet long, 2 feet wide, and 1 foot deep, and irrigates 22 acres. The dam is made of logs, stone, and dirt; is 20 feet long and 2 feet high. The soil is black, and produces 1 bale of cotton, 40 bushels of corn, and 280 bushels of sweet potatoes to the acre.

Woodward system.—The system of W. F. Woodward, which is just below that of Mr. Sparks, on Campswood Creek, was constructed in 1895, and irrigates 25 acres of black, loose limestone soil in the usual crops of this section (corn, potatoes, and sorghum), the yield per acre being 40 bushels of corn, 300 bushels of potatoes, and 5 tons of sorghum hay. The dam is 24 feet long and 2 feet high, and deflects the water into a ditch 2,100 feet long, 2½ feet wide, and 1 foot deep. It is taken out of the left bank, but crosses to the right bank.

McLaughlin system.—S. W. McLaughlin's ditch is just northwest of that of W. F. Woodward, and takes its water from the left bank of Campswood Creek, by a dam of logs, stone, and dirt 40 feet long and 3 feet high. The ditch is 1,950 feet long, 2½ feet wide, and 1 foot deep. The soil is similar to that of the preceding plants, 14 acres of which are irrigated in the three chief crops of the Barksdale section—corn, sweet potatoes, and sorghum.

Connell system.—On the farm of Mrs. W. A. Connell there occurs one of the springs (Connell Spring) that really are the source of the water of the upper sections of Nueces and Frio rivers. Its waters are led off into a ditch 800 feet long, 2½ feet wide, and 1 foot deep, which irrigates 24 acres, in corn and potatoes. The spring is near a stream, and the ditch runs parallel to the stream for about half its length and then crosses by a flume to the right bank.

Shockley system.—The next ditch below that of Mrs. Connell, on the short spring branch that is tributary to the East Nueces, is that of W. A. Shockley. The water is taken from the branch by means of a dam of logs, stone, and dirt 20 feet long and 2 feet high. The ditch is 2,700 feet long, 3 feet wide, and 1 foot deep. The system was constructed in 1894, and 50 acres are irrigated, the yield being 35 bushels of corn, 275 bushels of potatoes, and 5 tons of cane to the acre. Messrs. Woodward and Cunningham are joint owners with Mr. Shockley.

Lippard system.—The plant of J. K. Lippard, at Barksdale post-

office, was erected in 1892, and consists of a stone-and-dirt dam 15 feet long and 1 foot high across Campswood Creek and a ditch 1,500 feet long, 2 feet wide, and 1 foot deep. This plant irrigates 12 acres of the black, porous limestone soil planted in corn, sweet potatoes, and sorghum, producing 35 bushels of corn, 275 bushels of potatoes, and 5 tons of cane to the acre. The ditch is taken out of the left bank of the stream, but crosses the creek by a flume, thus irrigating land on both sides.

Casey, Taylor, and Graham system.—B. F. Casey, M. M. Taylor, and Oscar Graham (Barksdale) are the joint owners of a ditch that was constructed in 1898 to take water from a short spring branch tributary to the East Nueces. The ditch is 1½ miles long, 4 feet wide, and 2 feet deep, and irrigates 40 acres, the yield per acre being 40 bushels of corn and 1 bale of cotton. The dam is of logs and dirt, 40 feet long and 3 feet high.

Burr and Woods systems.—On the Pulliam Prong of the Nueces O. A. V. Burr and J. H. Woods each took out a ditch in 1899. That of the former is a half mile long, 2 feet wide, and 2 feet deep, and irrigates 50 acres of black bottom land, which yields 30 bushels of corn, 1 bale of cotton, 5 tons of cane, and 280 bushels of sweet potatoes to the acre. The dam is of rock, 150 feet long and 6 feet high. About one-fourth mile below the Burr dam is the dam of Mr. Woods. It is of logs, dirt, and brush, 50 feet long and 2 feet high. The 12 acres irrigated produce the usual yield of corn, cane, and potatoes.

Jones systems.—E. M. Jones, at Barksdale, built two small ditches in 1893. The upper is 600 feet long, 2 feet wide, and 1 foot deep, and irrigates 2 acres. The brush-and-dirt dam is 10 feet long and 3 feet high. The lower ditch is of the same length and dimensions and irrigates the same amount of land as the upper ditch.

Elms system.—The system of H. Elms is near Leakey, on the Rio Frio. It was constructed in 1894, and consists of a ditch on the east side of the river 1½ miles long, 4 feet wide, and 2 feet deep. The dam is of dirt and stone, 40 feet long and 1 foot high. Forty acres of corn, cotton, and sorghum are irrigated, yielding the usual quantities for this section.

Patterson systems.—About 4 miles northeast of Leakey W. B. Patterson has a brush-and-stone dam across the Rio Frio 45 feet long and 2 feet high, built in 1896. This supplies a ditch 2 miles long, with a top width of 5 feet, a bottom width of 3 feet, and a depth of 3 feet. It was first used in 1897, and commands 300 acres, 125 of which have been cultivated. Near Riofrio, just across the line in Bandera County, is the Patterson ditch, owned by a company composed of three men. It was constructed in 1868, is 2 miles long, 5 feet wide, and of a depth varying from 3 to 4 feet. The dam is of brush and gravel, 30 feet long and 4 feet high. The soil is black and sandy, and under irrigation is very productive. In 1901 about 700 acres of

cotton, corn, oats, and garden truck were irrigated. The yields per acre were 1 bale of cotton, 45 bushels of corn, 20 bushels of wheat, and 75 bushels of oats.

Etheridge system.—At Montell, on the Upper Nueces, Mr. J. H. Etheridge is the owner and operator of the Casa Blanca Irrigation and Mill ditch, which was constructed in 1894; it is 2½ miles long, 6 feet wide, 7 feet deep for the first half mile, and from 2 to 3 feet deep for the next 2 miles. Water is taken from Nueces River by a dam of loose rock, which raises the water to the ditch. The dam is 300 feet long and from 2 to 3 feet high. The soil irrigated is rich alluvial, and corn yields 40 bushels and cotton three-fourths of a bale to the acre. During the season of 1901 this ditch irrigated 100 acres.

Landrum system.—The plant of William Landrum is near Laguna. The source of supply is five large springs, which have been forced into one by means of dams. The dams range in length from 30 to 100 feet and in height up to 6 feet. Some of them are of rock, others of clay. The water of the springs is forced into a ditch three-fourths of a mile long, 4 feet wide, and 2 feet deep, and is capable of irrigating more than 100 acres, although only 30 acres are usually irrigated. The system was constructed in 1894 and 1895.

KERR COUNTY.

In Kerr County, on the headwaters of Guadalupe River, there are a few small plants. That of Robert Tedford, near the post-office of Japonica, takes its water from Honey Creek by means of a loose-stone dam 15 feet long and 2 feet high. The ditch is 900 feet long, 1½ feet wide, and about 1 foot in depth, and irrigates 4 acres of tomatoes, onions, sweet potatoes, etc.

The plant of Silas Welch, near the post-office of Mountain Home, takes its water from a spring by means of a rock dam 40 feet long and 2½ feet high. The ditch, constructed in 1901, is 6,000 feet long, 3 feet wide, and about 1 foot deep, irrigating 8 acres of corn and garden truck.

Kaiser system.—W. C. Kaiser early in 1902 installed a pump plant a mile below Mountain Home, on the left bank of Johnson Fork. A 16-horsepower gasoline engine operating a centrifugal pump against a lift of 25 feet irrigates about 50 acres in the ordinary crops. This plant paid for itself in one season.

Thrailkill system.—W. F. Thrailkill, just below Mountain Home, irrigates 10 acres from Smith Branch, a tributary of Johnson Fork of the Guadalupe. A small plank dam 1 foot high deflects the water into the ditch.

KIMBLE AND EDWARDS COUNTIES.

Irrigation in Kimble County is chiefly confined to the valleys of the creeks tributary to Llano River and its two branches, the North Llano and the South Llano. This is due to the great violence of the river during high stages and the consequent difficulty of building dams and

maintaining ditches. Capt. C. K. Gordon's is the only plant that takes its water direct from the river. There are no "company" ditches in the county; in some instances two or three men have formed partnerships, but all the plants are small. Few of them water more than 20 or 25 acres, while the average number of acres watered is much smaller. There are thousands of acres lying along the river and its larger tributaries that might be irrigated if sufficient capital were employed to successfully dam the river and use the water on a large scale.

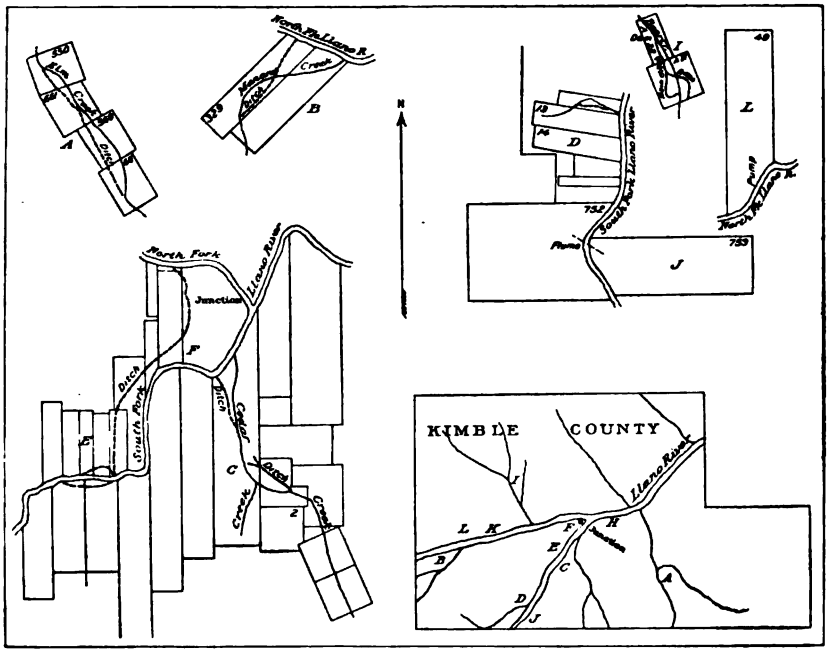

FIG. 14.—Map of Kimble County irrigation systems.

The following brief descriptions of the plants in Kimble County (see fig. 14) begin at the eastern end of the county and proceed westward. The plants are described in order downstream.

JOHNSON FORK OF LLANO RIVER.

The first stream on which there are irrigation plants is the Johnson Fork of the Llano, which joins the river about 5 miles below Junction City. There are four plants on this stream, as follows:

Moos system.—W. G. Moos's plant is three-fourths of a mile from the mouth of the Joy Branch, a small tributary of the Johnson Fork, about 11 miles above its mouth. It takes the water from the right bank of the Joy Branch, by means of an earth-stone-timber dam 60 feet long and 3 feet high. Thence the water is conducted along the right bank about 200 yards, and then is flumed to the left bank. The ditch is a fourth of a mile long, 1 foot deep, and flows at an average

depth of 1 foot. Eighteen acres are irrigated. The principal crop is corn, which produces about 30 bushels to the acre. Oats, wheat, cane, sweet potatoes, alfalfa, and garden vegetables are also grown. The yield of oats is about 40 bushels to the acre, and of wheat about 20 bushels. The cost of the dam was $25, of the ditch $25. The dam was first built by John Joy, prior to 1879.

Rembold system.—P. J. Rembold's plant is a little more than a half mile below the one just described, and is also on the Joy Branch. It was built by John Joy, prior to 1879. The dam is 60 feet long, of rock and gravel, and raises the water about 1 foot. The ditch is 300 yards long, 3 feet wide, and flows at a depth of 18 inches. Last year (1901) Mr. Rembold irrigated only 3 or 4 acres, but there are 67 acres of cultivated land within reach of the ditch. As many as 20 acres have been irrigated within recent years. Besides a garden the crop consists solely of Johnson grass. The cost of the dam was about $10, of the ditch $75.

Long system.—A. B. Long's plant is about 4 miles farther down the Johnson Fork. The water is raised 3½ feet by means of a 75-foot timber dam, consisting of upright timbers held in place by cedar posts and filled above with stones, gravel, and earth. Power is obtained by means of an undershot water wheel 8 feet in diameter and 5 feet long, operating two 6-inch force pumps of the walking-beam pattern, which raise the water 40 feet, through 100 feet of 5-inch iron pipe, to a flume. The flume conveys the water 100 feet, to a ditch 1½ feet wide, which carries it 600 feet farther, or to the field. Only 5 acres are irrigated, and only vegetables and fruits will be grown. It is interesting to note that an experiment is being made with strawberries. The cost of the dam was $50, of the flume and ditch $54, of the pipe $100, of the pumps $36, of the wheel $100, making a total of $340. The plant was constructed about 1898. This plant was recently sold to J. B. Bullard.

Owens system.—Eight miles from Junction City W. J. Owens operates a small pump plant, on the left bank of Johnson Fork of the Llano. A 12-horsepower steam engine operates a 3½-inch centrifugal pump against a small lift and irrigates a garden. This could easily be made to bring 200 acres under irrigation.

Armstrong system.—G. R. Armstrong's plant is on the Johnson Fork, about 3½ miles above its mouth. By means of a dam 86 feet long the water is raised 5½ feet. A race 86 chains long conducts it to a 15½-inch turbine, which operates a No. 4 submerged centrifugal pump. The pump raises the water 20 feet, at the rate of 600 gallons a minute (1⅓ second-feet). A reservoir 4½ feet deep, scraped out of the earth, and covering 1 acre, receives the water and distributes it to the field through a ditch a half mile long. Sixty-five acres of black loam are irrigated. The crop consists solely of alfalfa, which is grown for home use. The cost of the entire plant was $1,200.

CEDAR CREEK.

Cedar Creek, which flows into the South Llano about 1 mile southwest of Junction City, furnishes water for four plants, as follows:

Allen & Kelley systems.—J. A. Allen and W. H. Kelley own the first plant in partnership. It was constructed by J. H. Clements, and was completed in 1897. The ditch is three-fourths of a mile long, about 3 feet wide, and the water flows at an average depth of 10 inches. It takes water from one of the head springs of Cedar Creek, by means of a very simple dam of earth, logs, and stone. The dam is about 18 feet long and 2½ or 3 feet high. Immediately on leaving the dam the water is flumed across Cedar Creek, to the right bank, and soon branches. One of the branches is flumed across the creek, and after watering a small field is allowed to return to the creek. The other branch, at the point of separation, is flumed across a small draw, and after watering several small fields empties into the main ditch. Twenty acres of black soil are irrigated, usually planted in corn, oats, wheat, and cane. The yield of corn is about 40 bushels to the acre, of oats 60 bushels, and of wheat 23 bushels. The dam is about 5 miles above Junction City.

J. A. Allen and E. F. Kelley own the next plant, which is about a half mile below the one just described. This was the first dam built on the creek, being constructed about 1892. It is 60 feet long and is made of stone to a height of 4 feet. The ditch is three-fourths of a mile long and 3 feet wide, and carries a stream about 10 inches deep. The water is taken from the right bank of the creek about a half mile below the plant just described, waters a small field, is flumed across the creek and waters a second field, is again flumed to the right bank, and after watering a few acres is once more carried to the left bank and the remaining water is distributed through the largest of the fields belonging to the system. The large amount of fluming in this and the J. A. Allen and W. H. Kelley plant is made necessary by the sharp bends of the creek and by the precipitous bluffs. Thirty-three acres are irrigated, 8 acres belonging to Mr. Allen and 25 acres to Mr. Kelley. Corn and wheat are the chief crops.

Jarvis & Hodges system.—R. L. Jarvis and G. W. Hodges own the next plant, which is about 1½ miles downstream. The dam, which has just been replaced, consists of walnut-log pens securely bolted together and filled with stones. There are seven sections 10 feet long and two sections 8 feet long, all 6 feet wide. The upstream side is filled with gravel. The dam is 86 feet long and 4 feet high. The ditch is 80 chains long, 3 feet wide, and carries 6 inches of water. It emerges on the right bank of the stream and continues on that side. Forty-four acres are irrigated, 19 belonging to Jarvis, and lying nearest the dam, and 25 belonging to Hodges. The crops are corn, potatoes, wheat, and oats—chiefly corn, which yields about 40 bushels to the

acre. The cost of the dam was $40; the expense of maintaining is about $40 a year.

Taylor system.—W. W. Taylor's plant is just above the mouth of Cedar Creek. The dam is 60 feet long and 3 feet high, built log-pen style, and filled with stones and earth. The ditch is 2 miles long, 2½ feet wide, and carries 8 inches of water. It is on the left bank of Cedar Creek. It divides about 600 yards after leaving the creek, and one branch is flumed 75 yards, to the right side, where it waters the smaller field. Seven acres are irrigated. The crops are chiefly corn and potatoes. A garden is also watered. The cost of the dam was $25; the cost of the ditch, $300. The plant was constructed by Z. I., J. B., and J. A. Williams, about 1896.

BAILEY CREEK.

Jenson system.—On Bailey Creek, which flows into the South Llano about 10 miles above Junction City, is W. J. Jenson's plant. There is no dam, the water being taken direct from a spring on the left bank of the creek and carried in a flume across the creek and for about 350 yards along the left bank, where it divides. One branch is carried to a field on the right bank and the other across the creek again, in a 3½-inch iron pipe, and waters a field on the left bank. Only 4 or 5 acres are irrigated. Cane, corn, sweet potatoes, and garden vegetables are grown. The flume carries about 40 gallons a minute (one-tenth of a second-foot). The total cost of the plant was $100.

KYAC (CAJAC) CREEK.

Kyac (or Cajac) Creek, which flows into the South Llano from the left side, is the next stream that is used for irrigation. Four systems take water from this creek, as follows:

Dupuy system.—Maj. R. T. Dupuy's plant is about 2 miles from the mouth of the creek. There is no dam. The water is taken from a spring on the left bank of the creek, is flumed to the right bank, and is then carried by a 3-inch pipe to the field about 500 yards below. Seven acres are irrigated. The crops are oats and cane; a garden is also watered. The cost of the ditch was $30. The plant was constructed about 1883.

Griffith system.—S. A. Griffith's plant is about a half mile below the Dupuy plant. A lumber dam 50 feet long raises the water 2 feet. The ditch is a half mile long, 2 feet wide, and carries water to a depth of 6 inches. The water is taken from the right bank of the creek, but is soon flumed to the left bank, where it waters two small fields of 12 and 4 acres, respectively. The crops are chiefly wheat, corn, and vegetables. It is interesting to note that ribbon cane is successfully grown on a small scale. A yield of 200 gallons was raised from half an acre. This crop sells at 50 cents a gallon. The cost of the dam was $25; the

cost of the ditch $150. The plant was constructed by Q. Lowe in the eighties.

Bishop system.—J. L. Bishop's plant is a half mile below Griffith's. The dam is of stone, earth, and brush, 40 feet long and 18 inches high. The ditch is a half mile long, 2 feet wide, and carries a stream 6 inches in depth. The water is taken from the right bank of the creek. About 600 yards below the dam the ditch branches, one branch watering two fields near the point of separation, the other branch being flumed 106 feet across to the left bank, where it waters a third field. Fourteen acres of black loam are irrigated. The crops are sweet potatoes, corn, oats, millet, ribbon cane, and cotton. The noticeable feature about this plant is that 1½ acres were planted in cotton last year and one-fourth of an acre in ribbon cane, unusual crops in this county. The 1½ acres of cotton produced one bale; the yield of the cane was about the same as on Griffith's farm. The cost of the dam was $10; the cost of the ditch $150.

Calentine system.—F. L. Calentine's plant (on Mrs. Wooten's farm) is at the mouth of Kyac Creek. The dam, which is of logs, stone, and brush, is 80 feet long and 1½ feet high. The ditch is one-fourth of a mile long, 2½ feet wide, and carries a stream 5 inches deep. The water is taken from the right bank of the creek, is flumed 120 feet, to the left bank, and distributed to a field which lies along the South Llano. Twenty-five acres are irrigated, though 100 acres could with little trouble be put under the ditch. The chief crop is corn, 35 or 40 bushels of which were raised in 1900 on the irrigated land of this farm, while only 15 or 16 bushels were raised on the nonirrigated land. The cost of the dam was $5; the cost of the ditch $100. The system was constructed in the eighties.

FLEMMING BRANCH.

Flemming system.—O. B. Flemming's plant is on the Flemming Branch, a short distance above the confluence of that stream with the South Llano and about 15 miles above Junction City. His largest field lies along the Llano. The dam, which is of earth, logs, and stones, is 20 feet long and raises the water 1 foot. The ditch is a half mile long, 2 feet wide, and flows to an average depth of 6 inches. The water is taken from the right bank of the stream, is conveyed about 300 yards along the right bank, and then the ditch divides, one stream being flumed across to the left bank, where it waters a field of 5 acres, the other stream irrigating a field of 30 acres. The crops are corn, oats, cane, alfalfa, and a garden. The cost of the dam was trivial; the cost of the ditch was $75. The plant was constructed in 1890.

LITTLE PAINT CREEK.

Dougherty system.—The next plant in this vicinity is on what is known as the A. H. D. Dougherty place, at present (1902) occupied

by G. F. Wood. An earth-and-stone dam 50 feet long raises the water 1 foot. The ditch is three-fourths of a mile long, 2 feet wide, and carries a flow 6 inches deep. The water is taken from the east bank of Little Paint Creek, which flows into the South Llano from the left bank, about 1½ miles above its confluence with the South Llano. A large tank, constructed by throwing up embankments of earth, affords a storage reservoir 100 feet long, 20 feet wide, and 2½ feet deep. Twenty-five acres are irrigated. The chief crop has been corn, which yields 50 bushels to the acre. Twenty acres of cotton are to be planted in 1901. The cost of the dam was small; the cost of the ditch was $150.

SOUTH LLANO RIVER.

Baldwin system.—J. A. Baldwin has two small plants on the left bank of the South Llano, about 13 miles above Junction City. One of these plants makes use of a spring and has no dam and no ditch. A one-half-acre garden is irrigated. The other plant has a dam 10 feet long across a small spring branch which raises the water 1 foot. There are 100 yards of ditch 1 foot deep. Two acres of cane and corn are irrigated. The cost of the dam and ditch was trifling.

Hunger system.—T. Hunger has a small plant on the Ford Hollow Spring, a short distance from the South Llano and about 13 miles from Junction City. The water is taken directly from the spring, and is conveyed 1,150 feet, in a flume, to the garden irrigated. The flow is about 15 gallons a minute. A 1-acre garden is irrigated, from which Mr. Hunger derives a profit of about $250 a year. The flume cost $75. The plant was constructed in 1896.

Taylor system.—T. C. Taylor's plant is 17 miles above Junction City on the South Llano, though it does not take its water from the river. It is the last plant in Kimble County on the South Llano. The dam, which is of stone, is 5 or 6 feet long and raises the water about 10 inches. The water is taken from the Christmas Spring, on the left bank of the South Llano, and is carried under the river to the right bank in an iron pipe 300 feet long, and thence to the ditch through 1,326 feet of 8-inch sewer pipe. The ditch distributes it immediately to two fields of 14 and 11 acres, respectively. The principal crops grown are corn and cane, which are used at home for feed. The corn yields 40 bushels an acre. The cost of the dam was trivial; the cost of the iron pipe, $225; the sewer pipe, $331. The plant was constructed about 1892. Until the spring of 1901 Mr. Taylor used a flume instead of the 8-inch sewer pipe.

Barrett & Stephenson system.—C. C. Barrett and W. M. Stephenson own a plant about 2½ miles above Taylor's plant, just described, in Edwards County, about 2 miles across the Kimble County line. There is no dam, the water being taken directly from a number of beautiful springs which issue from the bluff on the left side of the South Llano. As a rule the bluff is too precipitous to permit the con-

struction of a ditch, hence the water is carried in a flume a large portion of the distance to the field, a tract of 25 acres about 1 mile down the river. The principal crops are corn, wheat, and cane. The cost of the flume and ditch was $200. It was constructed about 1895. This farm has only recently been purchased by Messrs. Barrett and Stephenson, and is generally known as the Black Place. The present owners intend to construct a new plant this summer (1901). They purpose to build a 4-foot dam across the Llano and use an 8-foot by 10-foot water wheel for power. This will operate an elevator pump to raise the water. Twenty-eight acres will be irrigated.

Huffman system.—One mile above Barrett's, on the South Llano, in Edwards County, is the plant of M. Huffman. There is no dam. The water is taken from a spring on the left bank of the river. The ditch is 300 yards long, 2 feet wide, and carries a stream 1 foot in depth. Seven acres are irrigated. Corn is the sole crop. The yield is 40 or 50 bushels to the acre. The cost of the ditch was $75. It was constructed by Henry Baldwin about 1895.

BEAR CREEK.

There are several plants on Bear Creek, a tributary of the South Llano, as follows:

Hall system.—The first plant in order coming down East Bear Creek belongs to Fred S. Hall. It is about 13½ miles above Junction City. The water is raised 4 feet by means of a timber dam, consisting of upright timbers held in place by cedar posts and filled with earth on the upper side. Below the dam the water falls on a cushion of cedar logs arranged parallel to the course of the stream. The ditch is a half mile long and 3 feet wide. The water flows about 9 inches deep, and irrigates a field of sandy loam containing about 9 acres. Last year (1900) the following crops were raised: Alfalfa and oats, 3 acres; garden, 1 acre; orchard, 2 acres; bermuda grass, 1½ acres; sweet potatoes, 2 acres. The sweet potatoes yielded 300 bushels to the acre, and were sold on the spot at 50 cents a bushel. The plant is now being enlarged and will be finished in time to irrigate the 1901 crop. About 800 yards below the dam is a branch ditch, which will be carried across the creek by means of 475 feet of 10-inch drain pipe laid under the creek. This will enable him to irrigate a field of 20 acres on the left side of the creek. The cost of the dam was $150; of the old ditch, $100, and of piping and new ditch, $150. The plant was constructed in 1895.

Reid system.—J. H. Reid's plant is on West Bear Creek, about 16 miles above Junction City. The water is raised 18 inches by means of a common earth dam about 25 feet long. It is then carried, at a depth of 4 inches, through a ditch 12 inches wide and a half mile long to a small field of 8 acres (in two patches). The crops raised in 1900 were corn, 2½ acres; sorghum, 2½ acres; potatoes, onions, etc. The

cost of the dam was probably not more than $5; of the ditch, about $50. The ditch is on the right bank of the stream.

D. L. Stewart system.—D. L. Stewart's dam is about 1 mile below Reid's. It was built in the eighties by John T. Mayes. It is 100 feet long and 3 feet high, and is made of earth and logs. The ditch is 1 mile long, 18 inches wide, and carries the water to a depth of 7 inches. The water is taken out of West Bear Creek, and is carried along the right bank for about 400 yards, when it is flumed across to the left bank. The field irrigated is mostly black loam, and contains 30 acres. The cost of the dam was $50; of the ditch, $150.

Morales system.—M. Morales's plant is on the left bank of West Bear Creek and is about 2 miles below that of D. L. Stewart. The dam is of stone and earth 150 feet long and 3 feet high. The ditch is about 2 feet wide and three-fourths of a mile long. This is one of the best as well as one of the most expensive ditches in Kimble County. Along part of its course it is walled with stone. Most of the remainder runs through a cut which averages about 5 feet in depth. The field irrigated contains 10 acres. The cost of the dam was $100; of the ditch, $175. The plant was constructed in 1899.

"*L. C. pasture*" *system.*—About a half mile below the Morales plant, and on the same stream, is the dam belonging to the "L. C. pasture," at present owned by G. D. Tarlton, of Hillsboro. It was constructed in the seventies, and is probably the oldest plant in the county. It is of earth, about 80 feet long and 2½ feet high. The ditch is 3 feet wide, a half mile long, and flows perhaps 800 gallons of water a minute (nearly 2 second-feet). It is carried along the left bank of the stream. The field of about 8 acres is used to raise alfalfa for the use of the ranch. A branch ditch also irrigates a small garden. The cost of the dam was about $30; of the ditch, about $40.

Alec. Stewart system.—Alec. Stewart's plant is just below the junction of East and West Bear creeks. It is 2 miles below F. S. Hall's and 1¼ miles below the "L. C. pasture" dam. The dam is similar to that of F. S. Hall, already described. It is 250 feet long and 3 feet high. The ditch is 1,000 yards long and 3 feet wide, and carries water to a depth of 12 inches. One hundred yards of the ditch is carried through a cut 4 feet deep. This is a new plant, having been constructed during the present spring (1901). The field irrigated, which contains 15 acres, is on the right bank of the creek. The cost of the dam was about $150; of the ditch, about $100.

Menge system.—William Menge's plant is on Walnut Creek, a tributary of West Bear Creek. It is about a half mile southwest of the dam of D. L. Stewart, and is a very small plant. The dam is 150 yards long and 12 inches wide, and flows about 50 gallons a minute. The field irrigated is a 1-acre truck patch.

Gordon system.—Capt. C. K. Gordon's plant is on the North Llano, 10 miles above Junction City. The water is lifted by means of a No.

7 centrifugal pump, operated by a 15-horsepower steam engine. The lift is 35 feet, 10 feet of which is by suction. Wood is used for fuel and costs practically nothing, as a quantity of driftwood is always on hand near the pump. The capacity of the pump with the present engine is 1,250 gallons a minute. There is no ditch. The water is discharged into a flume, by which it is carried 1,250 feet to the upper side of the field, crossing a road by means of an underground siphon. Between the road and the pump the flume is 20 inches by 12 inches, and is partially lined with zinc. Below the flume is 20 inches by 6 inches. No reservoir is used or needed. The plant is sufficiently large to irrigate 80 acres, but the field actually irrigated contains only 35 acres of black loam, with gravel subsoil. The crops raised are principally corn and alfalfa, which are used on the ranch. The average yield of corn is 50 bushels. The cost of the engine and pump was $800; of the house and appurtenances, $400; of the flume, $600; total cost, $1,800. The plant requires 1½ cords of driftwood to operate it one day. The wood is picked up near by. One engineer is required. A sawmill and a gristmill are also run by the engine.

Probable systems.—The flow of the South Llano at low ordinary stages is 90 second-feet near Junction City. A dam could be put in 10 miles above Junction City, and by bringing the ditch along the foot hills a mile west of the town and by taking it across the North Llano by a flume or inverted siphon 5,000 to 6,000 acres could be irrigated. In fact, the Ragsdale system did take out a ditch 4 miles above Junction City; but the dam was washed away some years ago, and it has never been rebuilt. It would also be possible to put in a system below the town by taking a ditch out on the north side of the main Llano. Any system put in will have to be very substantial, as the Llano is torrential at times.

SYSTEMS AT SAN ANTONIO AND VICINITY.

The irrigation ditches at San Antonio are historically the most interesting in the State, for here are found the oldest systems and structures, which have been in use more than a century. Additional interest is derived from the association of the ditches with the early missions and with the efforts of the Franciscan fathers to settle the Indians upon these lands and engage them in agriculture. These ditches traverse the city, often concealed by buildings and sidewalks.

MISSION AND NEIGHBORING DITCHES.

The original mission ditches, built by the Franciscan fathers between the years 1716 and 1744, are the Concepcion, the Alamo Madre, the San Jose, the San Juan, and the Espada, all dug to supply the lands belonging to the respective missions. In addition to these mission ditches, there was one, the San Pedro, which supplied water to the Villa Capital de la San Fernando, settled in 1730 by the

immigrants from the Canary Islands, and one built much later than any of the others, under the superintendence of the governor, Baron Ripperda, for the supply of the citizens of the town, and called the Upper Labor ditch.

UPPER LABOR DITCH.

Beginning at the head of San Antonio River, the most recent of the Spanish ditches—the Upper Labor—is the first encountered. It was begun in 1776, under the general direction of the royal governor, and was ready for use in 1778, care having been taken that there should be no infringement of the prior rights of the five missions and the Canary Island settlers. The ditch took its water from one of the large springs at the head of the river by means of a loose rock dam. It follows the contour of the land on the west side of the river and ends in San Pedro Creek. It once commanded about 600 acres, but is now out of use. In 1877 the city replaced the old loose rock dam by one of masonry, and built an extension to the ditch, called the Alazan branch. The latter was abandoned in 1896, because residences were built on the land irrigated.

ALAMO MADRE DITCH.

The Alamo Madre ditch, built between 1718 and 1744 to supply water to the Alamo Mission and irrigate its lands, derived water from the river on the east side just opposite the Upper Labor ditch, by means of a low dam. The ditch follows the contour of the land and runs through the business part of the city. Its length is 6 miles. It irrigated about 900 acres, but is now closed.

SAN PEDRO DITCH.

San Pedro ditch was commenced in 1738 and furnished water to the Villa de la San Fernando, the parish church of which, now called San Fernando Cathedral, is the geographic center of San Antonio. The water for the ditch, taken from the pool in San Pedro Park, follows the east side of the creek and runs through the center of the city, irrigating 500 acres of land below the town. Its length is about 4 miles, and it is 2 feet deep and 6 feet wide. The management of the foregoing ditches long since passed out of the hands of the landowners and into those of the city authorities and is now intrusted to a ditch commissioner appointed by the mayor. The annual water rent is $2 an acre.

CONCEPCION DITCH.

The next ditch of importance is the Concepcion, built in 1729 and abandoned in 1869, after being in use one hundred and forty years. It was discarded on account of the dam, which was in the center of the city, causing much damage from overflow when there was a rise in the river. This ditch was constructed to furnish water to the Mission de la Concepcion and was the largest of the old ditches.

OLD STONE AQUEDUCT CARRYING THE ESPADA DITCH ACROSS PIEDRAS CREEK.

SAN JOSE DITCH.

The San Jose ditch was built about 1720 to supply water to and irrigate the lands of the mission of that name, 5 miles below the town. The water was taken from the west side of San Antonio River, about 2 miles above the mission, and was returned to the river about 1 mile below. This ditch was abandoned about 1860.

SAN JUAN DITCH.

The San Juan ditch taps the river on the east side opposite the Mission San Jose. It follows the contour of the land and carries water down to the San Juan Mission. It was built in 1731 and is still in use. It irrigates more than 450 acres of land.

ESPADA DITCH.

The Espada is the lowest ditch taken from San Antonio River, though one of the oldest. The Spanish Government constructed it in 1824 and settled families on the land covered, assigning to each about 12 acres, known as suertes (swerties) and supposed to be the amount of land that could be irrigated from the ditch in one day. The ditch takes its water from the west side of the river, 6 miles below the city, by means of a loose rock-and-brush dam 270 feet long, built on a natural ledge of rock extending across the river, making the total height of the obstruction 8 feet. The dam consists of layers of brush weighted by loose rock, with gravel and earth thrown in front, forming a very effective dam, the rock becoming gradually cemented together by a deposit of lime salts from the water. It crosses Piedras Creek on a stone aqueduct, shown in Pl. VI, which consists of a series of massive arches that seem in as good preservation to-day as when constructed, more than a century and a half ago.

This ditch fell into disuse about twenty years ago and was abandoned until 1895, when A. Y. Walton, jr., who owned several suertes of land, organized the owners of the lands commanded by it into a company (the Espada Ditch Company), cleaned out, widened, and deepened the old ditch, repaired the dam, and made some change in its course, the total cost being about $3,000. The ditch is now 3 miles long, has a bottom width of 5 feet, and carries 10 second-feet of water. It commands 400 acres, nearly all of which is irrigated. The annual cost of keeping the ditch in good working order amounts to 25 cents an acre, the work being done by the members of the company. The manager notifies the members when work is to be done on the ditch, and no trouble has been encountered in repairing it on this labor-assessment principle. The general manager keeps a complete record of the hours and dates upon which each irrigator is to have water. Each member gets water every fifteen days, and is allowed all he wants, but he must use it only during the hours assigned to him.

The appearance of the crops under these ditches, even in a time of so abundant rainfall as the first half of 1897, is a remarkable proof of the value of irrigation. The land is mostly an alluvial valley soil, very productive when watered. On irrigated fields the customary yield is at least a bale of cotton to the acre, while for the last five years the average on unirrigated fields has been hardly more than one-fourth that amount. Truck farmers raise all kinds of vegetables from early spring until frost in the greatest profusion.

TRUEHART DITCH.

Three-fourths of a mile above the head of the dam which supplies the Espada ditch is the head gate of the Truehart ditch, which is now out of use.

ARTESIAN WELLS.

There is some irrigation from artesian wells practiced in and near San Antonio. Following are brief descriptions of the plants:

Kampman system.—The most extensive plant is that of Mrs. Caroline Kampman, who has three wells on her ranch, 3 miles east of the city limits. One of these wells has a flow of 1,500,000 gallons in twenty-four hours, under 20 pounds pressure, or 2.32 second-feet. It is 970 feet deep, and was drilled at a cost of $3,000. It is allowed to flow on 200 acres of the owner's land, most of which is in Johnson grass and sugar cane and needs only a small portion of the water. By a system of ditches or storage tanks this well would irrigate 1,000 acres of land. Almost all of the water from the other two wells is wasted. All of the water is impregnated with sulphur. Mrs. Kampman owns another well near the head of the river, 2½ miles northeast of the court-house, from which 26 acres are irrigated, but it could easily irrigate 300 acres.

Collins system.—Three miles west of San Antonio River, lying along the International and Great Northern Railroad, F. F. Collins has a farm of 140 acres which is irrigated from an artesian well 600 feet deep and 12 inches in diameter. The flow of this well has been estimated at 700 gallons a minute (1.5 second-feet). The water is clear and pure. The tract owned by Mr. Collins consists of 140 acres, all of which can be irrigated from this well. The farm is divided into tracts of 12½ acres each. A three-room house and the 12½ acres adjoining rent for $250 a year for land, house, and water. The latter is conveyed to the land by 4,000 feet of 6-inch pipe and 4,000 feet of 4-inch pipe. This method of conveyance guarantees a minimum loss by leakage and affords a most effectual control. The well is provided with two outlets, one of which supplies the pipe line on the farm, the other connecting to the reservoir. The reservoir is a triangular piece of ground covering 1 acre, one side of which is parallel to the track of the International and Great Northern Railroad. The capacity of the reservoir is 4,000,000 gallons, and the well fills it in seventy-two hours. It will be used to conserve the water supply, and will enable all irrigation

to be done in daylight. At night the flow will be shifted to the reservoir, and during the day water will be drawn from both the well and the reservoir.

Brady system.—The well of Thomas F. Brady is unique, in that it is deeper by several hundred feet than any wells in the vicinity. It is 6 inches in diameter and 1,450 feet deep. The water is soft and has the taste of rain water. It was noticed that the dry years affected it very slightly, but during the flush year of 1900 the water rose in the outflow conduit about one-fourth of an inch. Fifty acres of land are irrigated from the well, but it could easily irrigate as many more. Under present conditions the well is kept closed half of the time. The land is rented for $16 an acre, which includes the water rent.

Epp and Walters systems.—Just east of the Brady farm is the farm of John Epp, where a 4¼-inch well 884 feet deep irrigates 20 acres of forage, consisting mostly of cane and Johnson grass. Within a quarter of a mile of the Epp farm Mr. Albert Walters has a small well from which about 10 acres are irrigated.

Vandalle system.—About 2 miles west of the court-house, in the valley of Martinez Creek, Herman Vandalle has a 4-inch well 840 feet deep that irrigates 14 acres of garden truck. A small tank, 60 by 60 feet, has been constructed to conserve the flow and give a larger supply when necessary. The land rents for $25 an acre.

Koelblen system.—Near the Aransas Pass roundhouse Jacob Koelblen has a very successfully conducted irrigation plant from an artesian well. The well was bored in 1895. For the first 34 feet 10-inch piping was used. Into this was inserted an 8-inch pipe that extended to a depth of 200 feet, then 800 feet of 6-inch pipe was incased in this, and 1,027 feet of 4½-inch pipe completed the well to rock. The lower 70 feet was drilled into hard rock. A 4½-inch pipe leads from the well to a reservoir 72 feet by 30 feet, which borders on the east side of the San Pedro ditch, into which the waste water flows. The land irrigated lies on each side of the railroad track, the water being conveyed to it by pipes. Only 21 acres in garden are irrigated, but there is sufficient water to irrigate five times that amount. The water is rented out at $25 an acre. The drilling of the well cost $2 a foot, and the total cost of the plant, exclusive of land, was more than $4,000.

Dignowitty system.—A. F. Dignowitty owns two wells near San Antonio. The first well was bored in 1884, on the east side of Alazan Creek, 2½ miles northwest of the court-house. Water was struck at a depth of 160 feet, sulphur water at 210 feet. At 460 feet artesian water of 5 feet depth was struck, which shot 16 feet above the ground, giving a flow of 1,000,000 gallons per twenty-four hours. The water is clear and soft, of a temperature of 75° F., and is partly used for irrigation. The second well was bored in 1895. It is 1½ miles northeast of the court-house. At a depth of 20 feet a fine pottery clay 80 feet deep

was encountered; at 435 feet iron pyrites was met; and at 445 feet a vein of fine liquid asphaltum, which rose 45 feet in the well. At 456 feet a fine petroleum oil was struck; at 490 feet a substratum of clear fresh water, which rose to within 46 feet of the surface of the ground; at 500 feet a strong current of natural gas; at 525 feet a hard sandstone; at 540 feet a very hard white sandstone; at 550 feet another stream of water that rose within 35 feet of the top. The well stopped at 659 feet in hard, white rock.

SEWAGE FARM.

The sewage of the city of San Antonio is conducted about 4 miles southwest of the city and there utilized for irrigating purposes. Early in 1897 R. W. Hamilton & Co. made a contract with the city whereby the firm, in consideration of an annual payment of $1,000 to the city, was to receive all the sewage and the use of a tract of 350 acres of land. The company had to grub the land, erect houses, construct ditches, etc., before they could realize any income from their outlay.

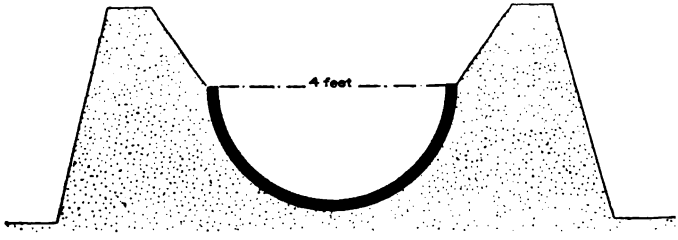

FIG. 15.—Cross section of sewer-farm ditch at San Antonio.

The sewage is delivered in the form of a half invert 44 inches in diameter, and to provide for an increased flow a dyke is constructed on each side of the invert, converting the whole into a canal the bottom of which is formed by the invert. (See fig. 15.) Three hundred and fifty acres are irrigated on what is known as the sewer farm proper, and the company has rented 150 acres from an adjoining farm, making in all 500 acres irrigated in 1901. In addition to this, about 3½ miles from the city the pipe line has been tapped and 50 acres are irrigated from the lateral. The flow is 10.8 second-feet, and 1,200 acres could readily be irrigated from it. At present the surplus is allowed to waste.

In September, 1901, the city leased the sewer farm and all of the sewage to R. H. Russel, J. A. Simmons, and others for a term of ninety-nine years. The lessees are to construct a ditch from the present outfall, a good and serviceable dam at Mitchells Lake, of a size sufficient to retain the surplus sewage of the city, and are to dispose of sewage by broad irrigation. They are also to guard the city against damages that may accrue from the sewage becoming a menace to private rights or a public nuisance. It is understood that the dam and ditch will

cost about $20,000. The lessees are to have the sole use of the sewage, and are to receive all rents from Hamilton & Co. for the two years their contract has to run.

MISCELLANEOUS SYSTEMS.

Halff Brothers system.—At the crossing of the river on Mitchell street, San Antonio, Halff Brothers have installed a 10-horsepower gasoline engine, which operates a rotary pump. The lift from the river level to the pump is 6 feet, and the water is pumped through 6-inch pipes alternately on the east and west sides of the stream. The capacity of the pump is estimated at 167 gallons a minute (0.35 second-foot). During the season of 1901 it irrigated about 20 acres, but had to be run only about one-tenth of the time. The crops raised were the usual garden truck, which found a ready home market.

Groos system.—Four miles below San Antonio, on the east side of the river, F. Groos has a pumping plant run by water power. It is on an old race, and consists of one 35-inch Leffel turbine operating two rotary pumps having 5-inch discharge openings and an estimated capacity of 400 gallons a minute each. The head on the turbines is 5½ feet, and it is estimated that 40 horsepower is generated. This will require a flow of 80 cubic feet of water per second. The San Antonio River has been known to flow only 10 cubic feet per second, and if all of this were utilized on the turbine it would generate only 5½ horsepower. The flow on December 31, 1901, was only 41 second-feet at the "hot wells," and in July, 1902, it was only 9 second-feet.

Praeger system.—Otto Praeger's plant, just north of the "hot wells," consists of a 10-horsepower gasoline engine and a double-suction rotary pump having 4-inch discharge. The water is raised into a flume, from which it flows into a ditch 600 feet long. Sixty acres of Johnson grass are irrigated. After a crop is cut and taken off, the water is immediately turned on until the ground is thoroughly saturated. Four weeks later the ground is flooded a second time, and two weeks later the grass is cut. Thus a crop is cut every six weeks. It requires 100,000 gallons of water per acre for a single saturation, and the plant waters one-half acre per hour.

Layton system.—Four and one half miles south of San Antonio is the Layton irrigation plant, which consists of a 15-horsepower Springfield engine operating a 6-inch Gould centrifugal pump. The lift is 17 feet and the estimated capacity 1,000 gallons a minute. The water is pumped from San Antonio River, and to deliver the quantity stated under the lift of 17 feet requires, with an efficiency of 80 per cent, only 4½ horsepower. Sixty acres of vegetables for the local markets are irrigated.

Brown system.—Five miles south of San Antonio, on the east side of the river, B. H. Brown irrigated 35 acres by means of a 5-horsepower engine operating a 4-inch pump. The water is pumped from San

Antonio River against a lift of 20 feet. The plant cost $400. The soil is black and very productive. Sugar cane, vegetables, corn, and oats are the crops raised.

Mission Farm Company system.—This company uses the natural outfall of the sewer and irrigates 50 acres of sorghum, Johnson grass, oats, and fruit trees.

Camille system.—The Camille plant, 4½ miles from San Antonio, pumps its water from the sewer outfall. The lift is 23 feet, and the pump has a discharge pipe of 4 inches diameter and a capacity of 900 gallons a minute. The soil is black. Eighty acres of vegetables are irrigated.

Meerscheidt system.—Near Prospect Hill, Meerscheidt Brothers irrigate 50 acres from a 12-inch artesian well. The water in the well rises to within 7 feet of the ground surface and is pumped into the ditches by means of a 12-horsepower Springfield engine and a 5-inch centrifugal pump. The capacity of the well is 750 minute-gallons, and this is sufficient to irrigate double the present acreage in dry seasons.

Pickett system.—Thirty miles below, on the same river, near Floresville, in Wilson County, is the plant of A. G. Pickett. It was set up in 1893, and consists of a 40-horsepower steam boiler operating a Blake duplex steam pump, which is connected to the boiler by a 2-inch steam pipe. From 12 to 15 horsepower is used at present, it being the intention of the owner to extend the plant, by the addition of more pumps, as more land is brought under irrigation. The average distance from the water to the pump is 15 feet and the average lift 50 feet. There is no reservoir, the water being pumped directly into the ditch. The total cost of the plant is estimated at $2,500, and it requires one man, at a cost of 12½ cents an hour, to operate it. The pump is covered by high water in the river from two to four times a year. This plant was built to irrigate from 300 to 400 acres, and has sufficient boiler capacity for that acreage, but will require additional pumps. The present pump has a 7-inch suction pipe and a 6-inch discharge, and is estimated to pump about 750 gallons a minute, or 1.67 second-feet, sufficient to irrigate from 75 to 100 acres, but only 50 acres of fruits were irrigated in 1901. The annual cost of water is estimated at from $2 to $6 an acre, according to the amount of rainfall and pumping.

State Agricultural and Mechanical College system.—The irrigation plant belonging to the experiment station of the State Agricultural and Mechanical College is a pumping plant deriving the necessary power from a windmill and a gasoline engine. The windmill is a steel Ideal, the original pump a deep-well pump having a maximum capacity of 80 cubic feet an hour. But this required a high wind to maintain the flow, and a 5½-horsepower (nominal) Weber & Co. gasoline engine, capable of exerting 4 actual horsepower was added. The pump has a cylinder 3½ inches in diameter by 36 inches long, with a

24-inch stroke when run by the engine and a 9-inch stroke when run by the windmill. The water is forced 600 feet to a reservoir 16 feet above the top of the well. The reservoir is 32 feet long, 52 feet wide, and 8 feet deep, and will hold about 100,000 gallons, 0.3 acre-foot. It was built by excavating to a depth of 4 feet and building around the excavation earthen walls of the same height, the total cost being $140. On account of the very porous nature of the soil all tanks in this region must be lined with artificial material—cement, asphalt, or coal tar. The reservoir at the experiment station is lined with a mastic consisting of 73 per cent sand, 25 per cent coal tar, and 2 per cent lime. The sand and lime are mixed together and the tar is boiled until it will string, when it is mixed hot with the other ingredients, and while hot is spread on the bottom and sides at the rate of 52 pounds to the square yard. On top is put a varnish formed by boiling pure coal tar and flashing it with a lighted match to burn off the light oils. The plant was completed in 1897, and it is estimated that 20 acres can be served by it. Gasoline costs 16 cents a gallon in Beeville, and 1 gallon used as fuel for the engine delivers about 1,900 gallons to the reservoir under the conditions stated. The cost of water per 1,000 gallons is 8.42 cents. Calculating the cost of a single irrigation at this rate, assuming that 2 acre-inches are supplied, 54,309 gallons (2 acre-inches) cost $4.58 per acre per application, or at the rate of $2.29 per acre-inch. Should land be permitted to become very dry before irrigation is resorted to the cost is increased correspondingly. Early in 1901 there was added to this plant a larger pump (5¾-inch cylinder), the capacity of which is 70 gallons an hour. A new well has been sunk 12 feet from the old well, the two being connected 60 feet beneath the surface of the ground, so that the water of one well will supplement that of the other well.

McDowell system.—W. G. McDowell, of Beeville, has a plant consisting of a 1½-horsepower gasoline engine pumping from a 70-foot well and irrigating 5 acres.

Beeville irrigated gardens.—These gardens have the most efficient plant near Beeville. It consists of a 4-horsepower gasoline engine pumping into a reservoir of 140,000 gallons capacity. Thirteen acres of vegetables are irrigated, but the plant could easily irrigate 20 acres.

Bee Star gardens.—The Bee Star gardens, of Skidmore, operate a plant consisting of an engine of 4 horsepower and an Ames pump with 4-inch suction pipe. The water is pumped from a 6¼-inch well 110 feet deep, and is discharged into a reservoir 120 feet in diameter, having a capacity of 500,000 gallons. Fifty acres of cauliflowers, cabbages, cantaloupes, etc., are irrigated. By judicious management of the water 100 acres could be irrigated.

Other truck systems.—The foregoing are types of many other systems in the country around and near Beeville. These plants generally consist of a small engine, a centrifugal pump, a surface reservoir,

and the necessary ditches. The following plants are in successful operation: S. A. McHenry (two plants), 27 acres; Carl Rankin, 12 acres; J. T. Holliday, 12 acres; J. K. Robertson, 7 acres; W. D. Messinger, 3 acres; A. M. Stoval, 12 acres; R. I. Eidson, 12 acres; J. H. Elliott, 4 acres, J. M. Chittim (near Normanna), 15 acres; James McCan (near Victoria), 25 acres.

Near Driscoll, in Nueces County, Charles Reynolds, George Reynolds, and Will Shealy are installing plants similar to the foregoing, while P. E. McNeill and John Clementson, at Wade's station, have each a plant in operation. The latter plants obtain the water from wells 150 and 190 feet deep, respectively, and during the current season 25 acres were irrigated.

King system.—On the King ranch, south of Alice, 46 artesian wells, of an average depth of 500 feet, furnish abundant water, and Mr. R. J. Kleberg, the manager, has commenced using this water for the irrigation of alfalfa; but this system is at present in its infancy.

Landa system.—Mr. H. Landa has just installed two irrigation plants on Comal River, at New Braunfels, for the purpose of irrigating about 70 acres of farm land. In one case the water is pumped from a lake near his flour mills and is forced through about 370 feet of 10-inch pipe into a canal in the field, being conducted through the canal to the highest point on the farm and then distributed by means of laterals to all parts of the tract. Intermediate laterals are also constructed at intervals along the main canal, and the water is carried by gravity to all minor elevations, the surface of the water in the main canal being higher than any point in the field. This system will water 25 or 30 acres. Mr. Landa's second system is supplied by a pump operated by a 20-horsepower gasoline engine, the water being elevated into a flume which leads into a canal that terminates on the bank of the river. This canal is constructed on the same principle as the one just described, the water being conducted to the highest portion of the field and distributed by means of laterals at intervals along its course. The tract to be irrigated by this canal contains about 40 acres. The canals are about 10 feet wide and the laterals 5 feet wide, constructed by building two parallel levees 10 feet apart, of sufficient thickness to prevent much seepage, the tops or crowns of the levees being made level, forming an elongated reservoir across the field, from which the water can be drawn at will. The total length of the main canal in the first system is 1,700 feet, the total length of the laterals 1,100 feet. The total length of the main canal in the second system is 2,200 feet, the total length of the laterals 2,700 feet. In the first case the water is raised 4 feet from the tank into the canal.

Locke system.—One mile west of New Braunfels Otto Locke irrigates 33 acres in orchards, nurseries, corn, potatoes, etc. A 12-horsepower Foos gasoline engine operates a 6-inch centrifugal pump against

a lift of 47 feet, raising 400 gallons per minute. The discharge pipe conveys the water to the highest point of the land, from which it is distributed by ditches to the lands watered. With the present prices of gasoline it costs $7 an acre per season. If continuously operated the plant could irrigate 50 acres.

Lenzen system.—The plant of G. P. Lenzen is located on the north bank of the Comal River in the suburbs of New Braunfels, and was first operated during the season of 1902. A 20-horsepower gasoline engine, operating a 6-inch Van Wie centrifugal pump against a lift of 60 feet, delivers the water into a 12 by 12 inch flume 500 feet long. Sixty acres in peas, sorghum, corn, cotton, and potatoes are irrigated at an average cost of $7 per acre.

Fischer system.—On the east side of the Guadalupe River, 1 mile below New Braunfels, near the bridge of the International and Great Northern Railroad, C. F. H. Fischer installed late in the season of 1902 a water-power irrigation plant. A dirt dam across the north channel of the Guadalupe deflects the water under a 7-foot undershot wheel, which operates a 3-inch Gould pump against a lift of 60 feet. The plant at present writing is an embryo of what is intended. A reservoir is to be constructed, and from this water is to be drawn to irrigate 50 acres in corn, cotton, grass, and gardens.

Bruemmen system.—One and one-fourth miles northeast of New Braunfels, W. Bruemmen uses an 8-horsepower Model gasoline engine to operate a centrifugal pump against a lift of 51 feet. The water is pumped out of the Guadalupe into a flume 1,100 feet long, which carries the water to the highest point of the 18 acres that are irrigated. The plant was put in late in the season of 1902, and its capacity has not been fully tested, but it has been found that it costs only $1.80 per day to operate the complete plant.

Starty system.—One mile north of New Braunfels, A. G. Starty has a small pump plant that derives its water from a well. A 6-horsepower gasoline engine runs a 4-inch Van Wie pump against a lift of 20 feet. The plant is located in the lowlands north of Landa Park, and during the current season 8 acres in cane, corn, and cotton were irrigated.

Dittmar system.—Five miles below New Braunfels, on the west side of Guadalupe River, Adolph Dittmar has a water-power irrigation plant. The water is pumped from the river by a Worthington pump having 10-inch discharge and a lift of 40 feet. The power is generated by one Risdon turbine working under a head of 5 feet. The dam is a natural formation in the river.

San Marcos Water Works Company system.—The San Marcos Water Works Company (William Green, president) transfers, by electricity, the power for its pump from a dam across San Marcos River, near the head of the stream. The distance from the water-power plant at the dam to the pump is 1,400 feet. The pump is a Van Wie centrifugal, having 18-inch discharge. The lift is only 8 feet, and it is the intention to bring 185 acres under irrigation.

Freeman systems.—About three-fourths mile below San Marcos, on the east side of the river, I. Freeman has a 16-horsepower gasoline engine which operates a 6-inch Morris centrifugal pump under a lift of 26 feet. The capacity is 1,312 gallons a minute, which would require only 8 horsepower. One hundred and twenty acres are to be brought under irrigation and cultivated in truck gardens.

J. R. Freeman has a 6-horsepower gasoline engine that runs a 4-inch Morris centrifugal pump, working under a lift of 26 feet. The estimated capacity is 350 gallons a minute. The plant cost $675. Ten acres of vegetables are irrigated.

Glover system.—The plant of Frank Glover consists of a 35-horsepower gasoline engine and a 12-inch Van Wie pump, operating against a lift of 35 feet. The water is pumped from San Marcos River, and it is intended to irrigate alfalfa and other crops. The soil is black and rich, and will produce well. The plant will irrigate 100 acres in 1902.

Lowman system.—Near the town of Staples, on San Marcos River, R. J. Lowman has a small irrigation plant in operation. The water is elevated to a height of about 21 feet, by means of an undershot water wheel carrying buckets on its circumference. The power is obtained from a 9-foot dam across the river. The capacity of the wheel is 300 gallons a minute. At present only 3 acres (a truck garden) are irrigated, and the wheel is not used to its full capacity.

Jones system.—About 5 miles below San Marcos, on San Marcos River, J. C. Jones irrigates a farm of 20 acres by means of the power obtained from a 7-foot milldam. He uses a 6-inch centrifugal pump having a capacity of 1,000 gallons a minute and one 2-inch rotary pump having a capacity of 125 gallons a minute. The water is lifted to a height of 31 feet. Part of it is pumped into a reservoir in the field, and the remainder is run directly from the pump to the field and there distributed. This is the first year the farm has been irrigated. The crop is to be corn and alfalfa. Cost of plant, $600.

Undershot water wheels.—Near San Marcos irrigation on a small scale is practiced by the use of undershot wheels, of wood, of the simplest form, with a metal bucket fastened to the perimeter of one side of the wheel in front of each paddle. These buckets fill in succession as the wheel turns and empty into a trough above, thus raising the water to a height of very nearly the diameter of the wheel. The wheel owned by Capt. John Richards irrigates 2 acres of grapes and vegetables, while that of D. C. Garret irrigates 7 acres.

SYSTEMS ALONG LOWER NUECES RIVER, LOWER RIO GRANDE, AND LEONA RIVER.

Nueces River rises in the Edwards Plateau and, with its tributaries, the Leona and the Frio, drains the portion of Texas between Brackett, San Antonio, Corpus Christi, Encinal, and Carrizo Springs. In this paper "the Lower Rio Grande" refers to the portion of that river

below Del Rio. The irrigation systems along the Nueces and its tributaries above the Southern Pacific Railroad are included in those of the Edwards Plateau.

LOWER NUECES RIVER.

Dolan system.—Going upstream, the first irrigation system is that of Pat Dolan, which is 6 miles below the crossing of the Southern Pacific Railroad. It consists of a 15-horsepower gasoline engine operating a pump, and with it he irrigates his garden and orchards. The cost of the plant was $735, and at the time of its erection gasoline was selling at 12 cents a gallon, and he says that irrigation under those circumstances could be made to pay.

COTULLA AND VICINITY.

Near Cotulla there are seven very effective pump-irrigation systems:

Copp system.—The plant of George Copp is the oldest, and originally cost $1,000. It consists of a 12-horsepower duplex steam engine and a 4-inch discharge pump, which, working against a lift of 45 feet, has an estimated capacity of 330 gallons a minute. The water is pumped from Nueces River and is delivered through 3,000 feet of pipe. The chief crop is Bermuda onions. It costs from $15 to $25 an acre to irrigate, depending upon the season. The yield is from 15,000 to 30,000 pounds an acre, and as the onions command from 1½ to 4 cents a pound the revenue is from $225 to $600 an acre. In all Mr. Copp irrigates 150 acres.

Butler system.—W. P. Butler's plant irrigates 10 acres by the use of a 4-horsepower gasoline engine and a centrifugal pump having a 3-inch discharge pipe. The water is pumped from Butler Lake and from Nueces River, and is raised 31 feet through 600 feet of delivery pipe. The system cost $700. The principal crop raised is Bermuda onions. The yield per acre and the price commanded are the same as in the case of Mr. Copp. Without rainfall the onions must be irrigated every fifteen days, while cabbages require water only once a month.

Kaley & Fuller system.—The plant of Kaley & Fuller consists of a 50-horsepower steam engine and a centrifugal pump having a 3-inch discharge. Water is pumped from Nueces River against a head of 26 feet. The estimated capacity is 600 gallons a minute, and 30 acres of Bermuda onions and cabbages are irrigated. The cost of the plant was $1,200. The yield and the revenue are the same as from the plants previously mentioned.

Uhl system.—The plant of Alexander Uhl cost $1,200, and consists of a 12-horsepower steam engine and a centrifugal pump having 6-inch discharge, operating against a lift of 28 feet. The capacity is estimated at 500 gallons a minute, and 35 acres of Bermuda onions are irrigated. The water is pumped from Harris Lake and from Nueces River, and is delivered through 1,150 feet of pipe.

Davis system.—The plant of J. H. Davis consists of a 12-horsepower steam engine and a duplex pump costing $1,000, and irrigates 100 acres of onions and tomatoes. The water is pumped from Nueces River, and is delivered through 2,000 feet of pipe. The capacity of the plant is estimated to be 200 gallons a minute.

Seafeldt system.—The plant of H. G. Seafeldt consists of a 15-horsepower steam engine and a duplex pump having a 4½-inch discharge, and irrigates 150 acres. Principal crop, Bermuda onions.

Hargus & Poole system.—The plant of Hargus & Poole consists of a 12-horsepower steam engine and a duplex pump having a 6-inch discharge. The plant cost $800. Water is pumped from Nueces River and is delivered through 500 feet of pipe.

UVALDE.

Kilgore system.—Six and a half miles west of Uvalde, on the left bank of Nueces River, is the plant of M. H. Kilgore and associates. A 55-horsepower engine operates a centrifugal pump, which delivers 1,500 gallons a minute (3⅓ second-feet) against a head of 73 feet. Wood is used as fuel, and as it is plentiful, the cost is nominal. The main ditch is 2 miles long, 6 feet wide at top, 2 feet at bottom; average depth, 2 feet. The plant was started in 1901, and 250 acres of the black, waxy, and sandy loam, most of it in alfalfa, were irrigated.

IDLEWILD.

Masterson system.—Near Idlewild, on the Southern Pacific Railroad, Branch T. Masterson has installed a pumping plant on Medina River. Steam is supplied from a 60-horsepower boiler, which operates the gin and mill, while the pump (8 and 12 by 12 by 10 inches) is connected direct. The head is 50 feet. The system was installed in the spring of 1901, and 200 acres, in oats and cotton, were irrigated. Medina River flows only about half of the year, but the plant is near a large pool in the river, which will furnish a supply at low stages.

CARRIZO SPRINGS AND VICINITY.

J. S. Taylor system.—Two miles below the iron bridge across Nueces River, on the road from Cotulla to Carrizo Springs, J. S. Taylor operates a pumping plant consisting of a 25-horsepower Buckeye engine, a 30-horsepower boiler, and an 8-inch centrifugal pump having 6-inch discharge. The lift is 25 feet, and 60 acres of onions, corn, and oats are irrigated. The water is pumped into a surface reservoir of about 2 acres area, located about 300 feet from the pump. The ditch leading from the reservoir to the field is one-fourth mile long. The pump is 100 yards above the dam mentioned below.

M. A. Taylor system.—On the ranch of M. A. Taylor a dam has been constructed across Nueces River about 2 miles below the iron bridge just referred to. The dam is 20 feet high in the center and 34 feet high on each side; wasteway 50 feet; length of dam about 170 feet. The dam is of live-oak log cribs filled with stones and backed

with stones, cement, gravel, and clay. The lake at low water is 20 feet deep and 5 miles long. To run the water out on gravity the dam would have to be built 29 feet high, which would give the water in the canal a total fall of 3 feet. The dam can be built 35 feet high, which would give a storage head of 9 feet, and would make a lake 10 miles long. The canal would be 1 mile in length and would turn the water out on gravity about 1 mile southeast of the ranch house. A storage dam 12 feet high and 200 feet long is to be constructed about three-fourths of a mile north of the soldier stone bridge, which would create a lake 10 feet deep and 10 miles long. To increase the height of the present dam to 29 feet in the center and 40 feet on each end, making it about 500 feet long, and to build the mile of canal 6 feet wide on bottom and with a slope of ½ to 1, would cost $6,000.

Artesian-well systems.—At Carrizo Springs artesian water can be obtained at a depth of about 100 feet. Artesian-well irrigation, however, is in its infancy. The wells 100 feet deep have a slow flow, although those of greater depth show a largely increased flow. The Paterson well is 590 feet deep and has a flow of about 200 gallons a minute, while the Campbell well, 5 inches in diameter, has a depth of 350 feet and a flow of 50 gallons a minute. These wells have not yet been used for irrigation, as they were completed late in 1901. Mr. Campbell has installed a 15-horsepower gasoline engine and a 5-inch centrifugal pump to augment his supply, and has constructed two earth tanks having a total area of 2 acres and an average depth of 8 feet. A well with a flow equal to the Patterson well could irrigate, under economical distribution, from 50 to 100 acres, depending on the season.

The Carrizo Springs.—No attempts have been made to utilize the flow of the famous Carrizo Springs for either power or irrigation.

LEONA RIVER.

The behavior of Leona River has been very irregular for several years. The Leona Spring, the source of its supply, is in the suburbs of Uvalde. It was dry in 1885, but soon revived and continued flowing until 1893, when it again stopped and has not flowed since. In 1893, before the spring ceased to flow, a pumping station for the city water supply was built on the banks near the spring, but a year or two after the spring failed, the pumping plant was transferred to its present location, within 150 yards of the court-house. At the new station a pit 15 feet by 15 feet by 24 feet deep was excavated, and the pumps were placed in its bottom. A well 4 feet by 7 feet was sunk in the bottom of the pit to a depth of 16 feet, or to the 49-foot level below the surface of the ground, from which water was pumped to a standpipe. At first the water rose in the well to within 35 feet of the surface, but in December, 1897, it was noticed that the supply was failing, and it continued to fail until May, 1898, when a second pit

10 feet by 10 feet by 9 feet deep was excavated on the southwest side of the first or main pit, and in it a well was sunk until its bottom was 63 feet below the surface. The pumps were then placed in the second pit, making their position about 33 feet below the surface. In January, 1899, however, the water level had fallen so low that it was necessary to bore in the pump well three wells of a depth of from 30 to 35 feet, reaching a total depth of 98 feet below the surface.

In June, 1899, after the heavy rains over southwestern Texas, known as the Brackett flood, the water was standing at about the 93-foot level and was slowly rising. On September 16, 1900, the water had risen to within 2 feet of the pumps, or to the 35-foot level. In other words, in fifteen months the water had risen about 58 feet, or nearly 4 feet a month. It continued to rise, and on December 1 had reached the pumps and arrangements were made to raise them. Accurate measurements during September, 1900, showed that the water was at that time rising in the wells at the rate of 4 inches a month.

Between the Leona Spring and the brickyard crossing, on the road from Uvalde to Pearsall, there are several small springs which contribute to the flow of the river, the largest being the Mulberry Spring. During the early part of 1900 this spring was flowing, but in September of that year its flow had ceased. On December 1, however, it had a flow of about 1 second-foot. In 1895 the discharge of Leona River at the brickyard crossing was 11 second-feet, but in June, 1899, the river was dry at the ford, and there was no water flowing between Uvalde and old Fort Inge, 4 miles below. On December 17, 1900, the flow at the brickyard crossing was 5 second-feet.

There are a number of irrigation systems along the river.

UPPER DITCH.

In 1874 a dam of dirt and logs was constructed across the river near old Fort Inge. It had a length of 53 feet and a height of 6 feet. The ditch known as the Upper ditch was taken out on the east side, the topography being such that a deep cut had to be made in the bank of the river. In all there are about 5 miles of ditches in this system, of the usual depth of 6 feet and of a width of 4 feet. Six hundred and thirty acres are irrigated from it. The crops raised are corn, hay, cotton, and onions. The yields per acre are 30 bushels of corn, 4 tons of hay, 1 bale of cotton, and 15,000 pounds of onions.

LOWER DITCH.

The Lower ditch was constructed in 1871. It is 4½ miles long, 6 feet wide, and generally about 3 feet deep. A dirt-and-log dam 50 feet long and 6 feet high forces the water into the ditch. The soil is a rich sandy loam. Three hundred acres are irrigated, the crops being corn, hay, and cotton. The yield is about the same as along the Upper ditch.

COMANCHE IRRIGATION COMPANY'S DITCH.

In Zavalla County, 2½ miles above Batesville, the Comanche Irrigation Company has taken out a ditch on the west side of Leona River. (See fig. 16.) It is 2½ miles long, 7 feet greatest depth, and 4 feet wide. The dam that deflects the water into the ditch is about 100 feet long and 15 feet high, and was first constructed in 1876, but had to be rebuilt. The ditch at first runs due west from the lake formed

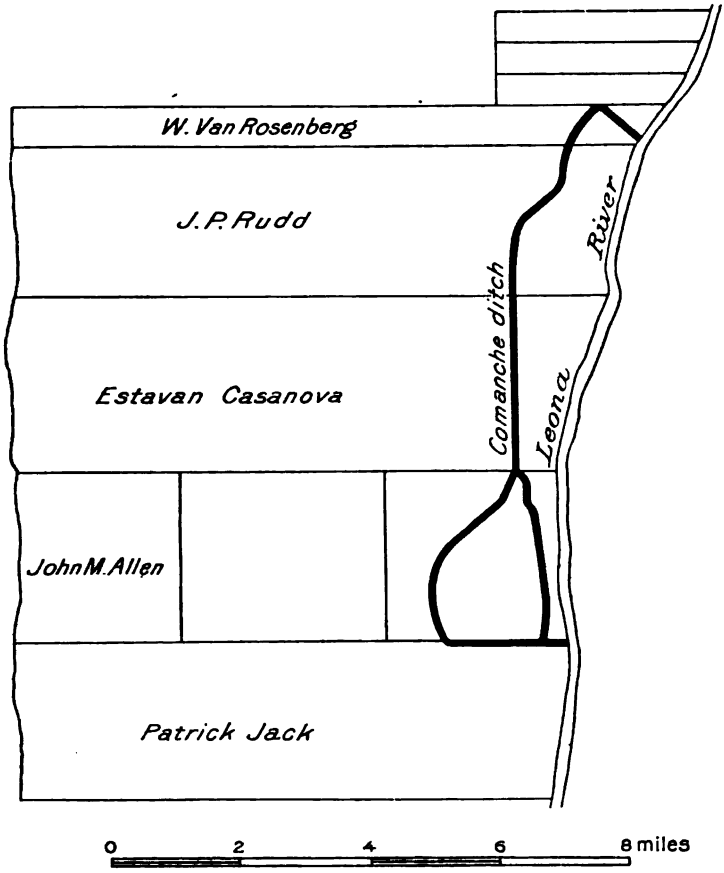

FIG. 16.—Map of Comanche Irrigation Company's ditch near Batesville.

by the dam for a distance of about 1 furlong, and then curves to the south, and for 2 miles runs almost parallel with the river, and then branches, in order to bring more land under it. The soil is a dark sandy loam of great depth, rich and easily cultivated, and is known as black mesquite. The company irrigates 500 acres of corn, oats, cane, hay, cotton, fruits, and garden truck. The corn yields 35 bushels and the cotton 1 bale to the acre.

LOWER RIO GRANDE.

The Rio Grande Valley forms one of the most inviting fields for irrigation on a large scale that can be found in Texas. At Brownsville the valley is 35 miles wide, decreasing slightly upstream toward Hidalgo. Five miles above Hidalgo the width suddenly decreases, and from there on it varies considerably, being at most a few miles and often almost nothing. There are from 180 to 200 square miles of rich and fertile valley land that could be brought into active production by clearing up the land, constructing canals, and installing pumping machinery. The minimum flow of the river at Laredo is 2,500 second-feet, and remembering that 1 cubic foot per second will irrigate and keep flooded 50 acres of rice, it can readily be seen that the natural factors of soil and water only await utilization to inaugurate a successful rice and sugar industry along the Rio Grande. Sytems have already been built near Eagle Pass, at North Laredo and Hidalgo, and at Brownsville and vicinity, as described on the following pages.

EAGLE PASS.

Dolch system.—Just below Eagle Pass L. F. Dolch has put in a large pumping plant with which he will irrigate 400 acres of the Rio Grande bottoms. His machinery consists of a 125-horsepower Frost engine and two 80-horsepower boilers, operating two centrifugal pumps of 14-inch discharge against a lift of 45 feet. The estimated capacity is 22 second-feet. The plant is on the banks of the river, the pumps being in a pit 31 feet deep and 20 feet in diameter. The water is drawn from the river through a 14-inch suction pipe 300 feet long, and is discharged through 1,100 feet of 14-inch discharge pipe.

NORTH LAREDO.

In North Laredo, on the banks of the Rio Grande, there are three pumping plants for irrigation.

Nye system.—The plant of F. C. Nye consists of two 60-horsepower boilers and a Quincy duplex pump having a capacity of 800 gallons a minute (1.8 second-feet) against a head of 65 feet. The water is pumped from a well on the sloping banks of the river. The well extends below the level of low water and is connected to the river by a pipe. It is well built, about 12 feet in diameter, and is lined with brick. The pump is on a platform in the well. Only 12 acres are irrigated, but 75 acres could easily be served. The pumps are usually operated eleven hours a day, at a cost of $7.50 for repairs, coal, engineer, etc. The fuel used is the Pecos coal, which costs $1.50 a ton. The land is watered twice a month, and the yield is 21,000 pounds of onions to the acre for unfertilized land and 31,000 pounds to the acre for fertilized land.

Lithgow system.—The plant of F. H. Lithgow is about a half mile

below the Nye plant, and consists of a 20-horsepower gasoline engine and an 8 by 10 Van Wie triplex pump, which has a capacity of 400 gallons a minute against a head of 70 feet. The water is delivered through a pipe 830 feet long. The cost, including oil, is $3.25 per day of eleven hours. The engine runs without supervision and can water 30 acres a day. The soil is alluvial, 10 feet deep, underlain with clay. The crops raised are onions, tomatoes, cabbages, carrots, turnips, watermelons, and cantaloupes. In all 38 acres are irrigated.

Madrigal system.—The plant of S. V. Madrigal, which adjoins the Lithgow plant, consists of a 10-horsepower Weber gasoline engine and a 6 by 8 triplex pump raising 200 gallons a minute against a lift of 70 feet. One acre a day is irrigated, and each section of land is watered every twelve to fifteen days. The pump is an upright direct-stroke and is operated by a belt from the engine. The suction pipe is a 4-inch, and the water is pumped from a well connected with the river similarly to that of the Nye plant. The well is 5 by 5 feet and is lined with timber.

HIDALGO.

Closner system.—At Hidalgo, down toward the mouth of the Rio Grande, is a steam pumping plant owned and operated by John Closner. It consists of a 50-horsepower engine operating a centrifugal pump having a capacity of 6.7 second-feet. The water is pumped from the Rio Grande, and 200 acres of sugar cane and corn are irrigated. The principal crop is sugar cane, which is manufactured into sugar that finds a ready market. This plant has proved one of the most successful in Texas, and it is paying an excellent return for the outlay.

BROWNSVILLE AND VICINITY.

Brulay system.—George Brulay, of Brownsville, has a pumping plant worthy of attention. Is is 8 miles below Brownsville, in Cameron County, and was completed and first used in 1896. It consists of two boilers, having an aggregate capacity of 100 horsepower, and a 45-horsepower Morris centrifugal pump, having a maximum capacity of 8,000 gallons a minute, or 17.82 second-feet. The total lift is 22 feet, and when in use the pump is run about fourteen hours a day. It is designed to cover 300 acres, but so far only 240 acres, planted in sugar cane, have been irrigated. A high-grade sugar is made from the cane juice.

Goodrich systems.—E. H. Goodrich reports having installed a 10-horsepower Priestman engine in a resaca on his place, 6 miles north of Brownsville, in March, 1897, but he has used it very little, owing to favorable weather and to the fact that the ditches are not yet finished. With two 12-foot windmills on the same place he can irrigate 35 acres. He also irrigates between 15 and 18 acres on his place, 3 miles north of Brownsville, by means of a 14-foot windmill pumping

from a well in the bank of a resaca. The distance to the water varies from 5 to 12 feet, and the pumps, which are three in number, discharge into a flume connected directly with the ditches. The total cost of the latter plant was $300.

Tijerina system.—Tomas Tijerina, Sabos Cavazas, and Pedro Cerna, on a farm about 9 miles above Brownsville, raise sugar cane by subirrigation from the Rio Grande. The cane is ground in an old-fashioned sugar-cane mill, and the juice is caught and boiled down to a consistency that will readily mold. The molds are of the form of a frustum of a cone of about 4 inches base. After the sugar is molded it is known as *piloncillo.* It is $\frac{98}{100}$ pure sugar, is hard, breaks readily, and the light varieties have a taste similar to that of maple sugar. The lumps are wrapped in the foliage of the cane and are put up in packages of 150 pounds, forming what is called a cargo, equal in volume to six American bushels. *Piloncillo* is one of the chief commodities of the Mexicans of the Lower Rio Grande.

COLORADO VALLEY SYSTEMS.

The irrigation systems in this section include those in the Colorado Basin which are within a short distance of the river or immediately upon it. The Edwards Plateau is drained on the north by the tributaries of the Colorado, but the irrigation systems on those tributaries are described in the Edwards Plateau group, pages 25 to 51.

STERLING COUNTY.

The first systems along the Colorado or its branches are in Sterling County, along the North Concho. There are two of them, one owned by the McGee Irrigation Company and the other by J. N. and J. H. Kellis.

McGee Irrigation Company system.—This plant is 5 miles from Sterling City. The main ditch is on the southwest side of the river. It is 2 miles long, has a top width of 6 feet, a bottom width of 4 feet, and carries about 1 foot of water. It was begun in 1892 and was first used in 1894. The water is raised by a loose-rock dam 125 feet long and 6 feet high, built across the river. The total cost was $1,500, and it commands 250 acres, only 70 of which are irrigated. The principal crops, in order of their importance, are cotton, corn, sorghum, oats, sweet potatoes, alfalfa, and vegetables. The ditch is kept in repair by each stockholder doing his share of the work.

Kellis system.—The Kellis plant was constructed in 1889 on the northeast side of the North Concho. The ditch is 1 mile long, top width 6 feet, bottom width 4 feet, depth 2 feet. The water is deflected into the ditch by a loose-rock dam 50 feet long and of an average height of 5 feet. The soil irrigated is a loose gray loam. Fifty acres are served from the ditch, the crops being cotton, corn, cane, oats, potatoes, and Johnson grass.

IRION COUNTY.

Near Sherwood, in Irion County, there are three dams across Spring Creek, the headwaters of Concho River. These are known as the upper, the middle, and the lower dam, and, although injured considerably by the floods of 1900 and 1901, each dam has its irrigation system in the chocolate-colored loam of the river valley. The upper and middle dams are 3 and 2 miles, respectively, above Sherwood. The ditches from them irrigate 266 and 216 acres. The lower, or Steinbaugh dam, is a half mile from Sherwood, and the ditch from its reservoir irrigates 153 acres. The crops raised command the highest market price, as competition is practically out of the question. The Sherwood system commands in all 635 acres.

TOM GREEN COUNTY.

In Tom Green County the irrigation facilities furnished by Concho River and its numerous branches and tributaries are among the best to be found anywhere in western Texas. These have been only partially utilized, however, in separate systems, by individuals and small companies, making the cost of maintenance much greater than if consolidated. Nevertheless they have been fairly successful, and have certainly reduced the cost of living in that section, making foodstuffs, especially vegetables, much cheaper and more abundant. Eleven plants are reported in the county—six on the South Concho, one on the North Concho, one on Lipan Creek, and one each on Spring Creek and Dove Creek. The location of all of these ditches, except the one on the North Concho (the Williams or Joe Glenn ditch) and the one on Lipan Creek (the Kelly ditch), is shown in fig. 17. The total area irrigated in the county is 3,500 acres.

Williams or Joe Glenn ditch.—The ditch of Mrs. W. D. Williams, known as the Joe Glenn ditch, is on the North Concho, 1½ miles west of Water Valley. It is 3 miles long, 8 feet wide on top, 4 feet wide on bottom, and 2½ feet deep. It was first used in 1886, and is supplied with water by a rock dam across the river, 100 feet long and of an average height of 8 feet. The total cost of the system was $3,500, and it commands 350 acres, 225 of which have been irrigated, two-thirds in cotton and the remainder in different sorghums and oats.

Glenmore farm ditch.—Two miles southeast of San Angelo is the celebrated Glenmore farm, sometimes known as the Cunningham farm, owned by A. F. Mabry. In 1891 a timber dam of the kind known as "turtle back," 74 feet long and of an average height of 7 feet, was built across the South Concho, and from it a ditch 4 miles long and of an average width of 6 feet and an average depth of 14 feet conducts the water to the land irrigated. The dam cost $4,000 and the ditch $500 a mile. The soil is a black sandy loam, and alfalfa, celery, cotton, and garden truck are produced in abundance. About 20 acres

are confined to a garden. The famous Glenmore celery is produced here. Ninety acres are irrigated, and the yield of alfalfa is 4 tons to the acre.

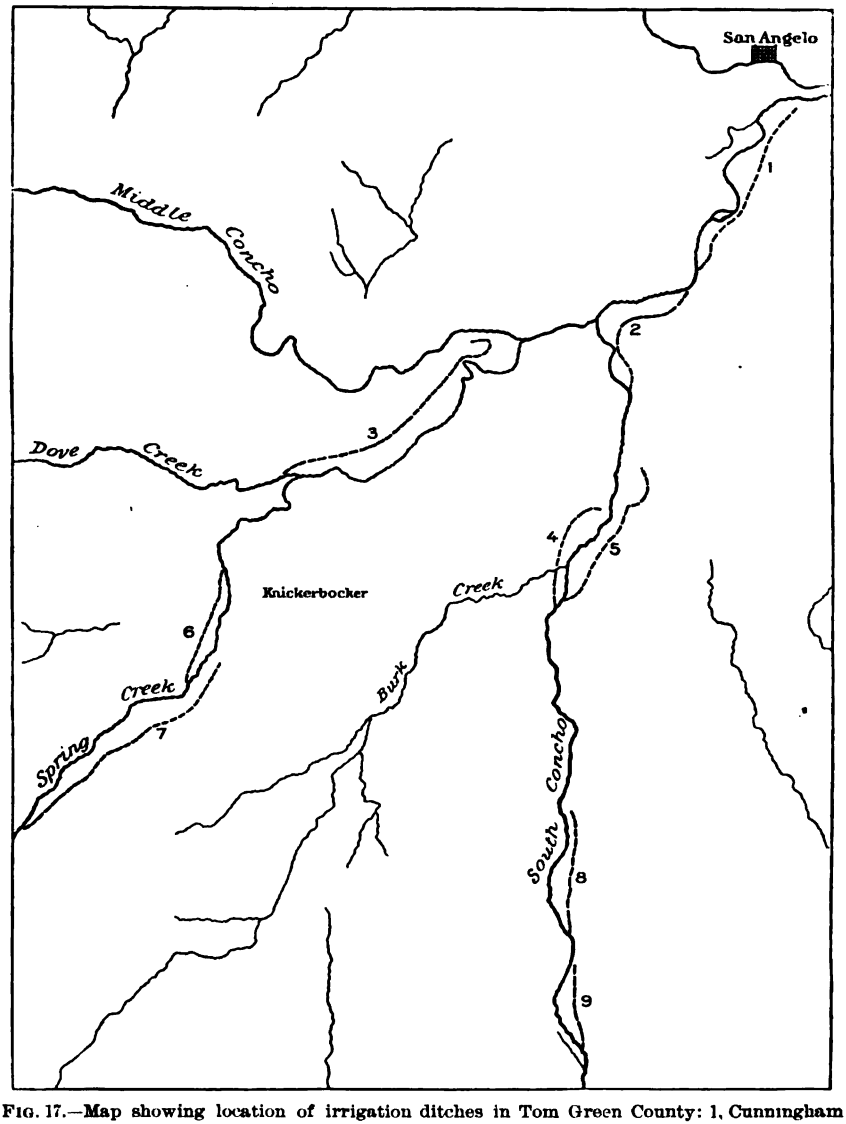

FIG. 17.—Map showing location of irrigation ditches in Tom Green County: 1, Cunningham ditch; 2, Bismarck ditch; 3, Twin Mountain ditch; 4, Gardner ditch; 5, Metcalf ditch; 6, Baze ditch; 7, San Jose ditch; 8, South Concho Irrigation Company ditch; 9, Miles ditch.

Bismarck ditch.—The Bismarck ditch, owned by Jones & Payne, of San Angelo, is 7 miles south of San Angelo, on the east side of the South Concho. It was projected by the Ben Ficklein Irrigation and Manufacturing Company, and was constructed in 1875. It is 4 miles

long, 10 feet wide, and of an average depth of 2.9 feet. A brush-and-rock dam 80 feet long and 10 feet high deflects the water into the ditch. The dam cost $1,500 and the ditch cost $900 a mile, the total cost being about $5,000. The soil is black loam; the crop raised oats, corn, cotton, sorghum, and Johnson grass. The yield per acre is 60 bushels of oats, 20 bushels of corn, two-thirds of a bale of cotton, and 3 tons of hay. Six hundred acres are irrigated. The most modern methods are used on this farm. The ground is plowed by use of a 20-horsepower traction engine, which, with three disk plows, breaks up 25 acres per day. Two crops are often raised on the same land in one year. When the small grain is cut, a crop of turnips is immediately planted, and these are off in time for small grain in the fall.

Gardner system.—The plant of A. F. Gardner is on the west side of the South Concho, 12 miles south of San Angelo. A dam of brush and rock 70 feet long and 6 feet high, costing $400, was constructed in 1883. It deflects the water into a ditch 2 miles long, 6 feet wide, and of an average depth of 16 inches. The ditch cost $250 a mile, making the total cost of the system $900. In all 70 acres of sandy loam are irrigated. The crops are oats, cotton, and Johnson grass, the yield being 60 bushels of oats, two-thirds of a bale of cotton, and 3 tons of grass to the acre.

Twin Mountain ditch.—The Twin Mountain ditch is on the north side of the river, at Spring Creek, 12 miles southwest of San Angelo. It is owned by Charles Mott, of San Angelo. A wooden dam 80 feet long and 7 feet high, built in 1885 at a cost of $2,000, deflects the water into the ditch, which is 3 miles long, 12 feet wide, and 15 inches deep, and cost $500 a mile. Under this system 300 acres of black loamy land are irrigated. The crops are oats, cotton, and Johnson grass, the yield the same as elsewhere in this locality.

Metcalf ditch.—The Metcalf ditch (owned by Metcalf & Sims) is 12 miles south of San Angelo, on the east side of the South Concho. It is 4 miles long, with an average top width of 12 feet, a bottom width of 8 feet, and a depth of water of 1½ feet. It was begun in 1887, and the first mile was completed the next year, but the ditch was not entirely completed until 1896. It takes water by means of a brush-and-stone dam 200 feet long and 7 feet high, which extends across the river. The cost of the dam was about $500, the cost of the main ditch $500 a mile, and the cost of the laterals, of which there are three, $250 a mile, making the total cost, with incidentals, $7 to each of the 470 acres now irrigated. The repairs, which are maintained by the tenants, may be estimated as amounting in labor to 75 cents an acre. The crops are Johnson grass, cotton, corn, oats, wheat, and garden truck.

South Concho Irrigation Company ditch.—The plant of the South Concho Irrigation Company was constructed in 1881. It is on the east side of the river, 20 miles south of San Angelo. The brush-and-

rock dam is 70 feet long and 7 feet high, and cost about $600. The ditch is 3 miles long, 7 feet wide, and averages 16 inches in depth. It cost $400 a mile. The soil is rich, black loam, and the 220 acres irrigated yield 60 bushels of oats and 3 tons of Johnson grass per acre.

San Jose Irrigation Company ditch.—The dam of the San Jose Irrigation Company (of which Joseph Tweedy, of Knickerbocker, Tex., is the secretary) is on Dove Creek, about 8 miles from Knickerbocker. It is composed of brush, rock, and gravel; is 900 feet long and 8 feet high, and cost about $1,250. The annual repairs cost from $50 to $100. The dam deflects the water into the ditch, which is 6 miles long, 8 feet wide, and 1½ feet deep, and cost about $300 a mile. The soil is chocolate-colored loam, and 1,400 acres are usually irrigated. The crops are oats, corn, cotton, sorghum, and Johnson grass, the annual yield per acre being 40 bushels of oats, 20 bushels of corn, three-fourths of a bale of cotton, and 3 tons of hay. This is by far the largest irrigation system in the Colorado Valley.

Baze irrigating ditch.—Five miles below the dam of the San Jose Company and 3 miles from Knickerbocker is the dam which feeds the Baze irrigating ditch. This was constructed in 1875 and is now owned by Dr. Boyd Cornick and others. It is of wood and rock, 48 feet long, and 8 feet high, and cost about $500. The ditch is on the west side of the creek. It is 3 miles long, 7 feet wide, and 1½ feet deep. The soil is similar to that of the San Jose Company's tract. One hundred and sixty acres of oats, alfalfa, and cotton are irrigated.

Kelley system.—Twenty miles southwest of San Angelo, on Lepan Creek, is the system of Mr. W. S. Kelley. In 1894 he constructed a wooden dam 40 feet long and 4 feet high, which feeds the ditch. The latter is 1½ miles long, 4 feet wide, and about 1 foot deep. The soil is a sandy loam. Forty acres of oats, Johnson grass, and garden truck are irrigated. The dam cost about $150 and the ditch $175 a mile.

BROWN COUNTY.

Swinden Pecan Orchard Company.—Near Brownwood, in Brown County, about 120 miles east of San Angelo, there is a large area suitably located for irrigation on an extensive scale. In it is the plant of the Swinden Pecan Orchard Company, which consists of a centrifugal pump operated by an 80-horsepower engine, pumping 3,000 gallons a minute, or 6.84 second-feet. The water is carried by a flume 4,000 feet long to a reservoir formed by an earthern dam 400 feet long and of a height varying from 2 to 15 feet. The dam is at the foot of gently sloping land, and forms a triangular reservoir covering 55 acres. The reservoir is designed to irrigate the 400 acres of level land lying along the Pecan Bayou, from which the water is pumped to fill it. A small stream is also dammed and turned into the reservoir. The 400 acres commanded by the reservoir are planted in pecan trees, making the largest orchard of that kind in the world. The irrigation plant was put in chiefly to enable the owners to practice

truck farming and the growth of small fruits between the rows of trees while waiting for the latter to mature. The soil is a rich black and chocolate colored loam. A great mistake was originally made in having the reservoir so large and shallow. Evaporation and seepage were in this way increased. To reduce the loss by evaporation an inside dam has been constructed, decreasing the area of the reservoir.

Fairland irrigated farm.—The Fairland irrigated farm, owned by J. F. Smith and brother, is a short distance from Brownwood. Two pumping plants have been installed. The first one consists of an Ivens single-suction centrifugal pump, operated by a 50-horsepower Chandler & Taylor plain slide-valve engine. With an average lift of 15 feet 4,000 gallons a minute (9 second-feet) can be discharged through the 10-inch discharge pipe. The second plant consists of an Ivens double suction pump having a 13-inch discharge pipe, and driven by an 80-horsepower Nagle engine, which delivers 5,000 gallons a minute (11 second-feet) against a head of 30 feet. The length of the ditches is about 4 miles, the width 6 feet at top and 3 feet at bottom, and the depth 1 foot. There are 400 acres under ditch, and 1½ bales of cotton per acre are produced from irrigated land, while only one-fourth bale can be produced from unirrigated land. The first plant cost $2,000, the second plant $3,000, making a total of $5,000. In 1900 high water destroyed the crop.

MILLS COUNTY.

In Mills County several pumping plants were formerly operated along Colorado River, but the high water in June, 1899, and in April, 1900, damaged them by either submerging the pumps or destroying ditches and crops to such an extent that some of the owners were discouraged and never repaired the plants.

LAMPASAS COUNTY.

Finlan system.—One mile east of Lampasas Mrs. Owen Finlan for years operated a windmill plant, the water being pumped into a cement tank 60 feet in diameter. In 1901 a 4-horsepower gasoline engine was added. This plant is on the south bank of the Sulphur Fork of Lampasas River, and pumps the water from the pond or lake formed by Donovan's dam. The water is raised 20 feet by a bucket pump, and is delivered into a flume which conveys it to the cement tank. From the tank the water is conveyed to the land through a system of ditches. Fifteen acres of truck gardens are successfully irrigated. The yield of onions and sweet potatoes is exceptionally large. Below the plant of Mrs. Finlan there is a fertile valley that could easily be brought under ditch.

TRAVIS COUNTY.

Near Del Valle, in Travis County, there are two pump plants. That of George Begg consists of a 60-horsepower engine, which operates a 10-inch centrifugal pump against a lift of 45 feet; 200 acres in

ordinary crops will be irrigated. The plant of N. H. Shappard consists of a 12-horsepower engine operating a 6-inch centrifugal pump against a lift of 40 feet. Only 20 acres were irrigated this season (1902), but plans have been formed to enlarge the system by adding a 45-horsepower boiler and two 10-inch centrifugal pumps.

SYSTEMS NORTH OF COLORADO RIVER.

Irrigation in this region is rare, for two reasons: (1) The section (the eastern portion) where the streams would furnish water for irrigation has sufficient rainfall to raise crops unaided; and (2) the western portion, including the Staked Plains, has no streams available for irrigation, the underground waters are still undeveloped, and the construction of impounding reservoirs has commended itself neither to private enterprise nor to public favor.

BELL COUNTY.

Hoover system—One mile west of Killeen, in Bell County, A. J. Hoover has shown what could be done by windmill irrigation. His plant consists of a Dandy windmill, 13 feet in diameter. The water is pumped from a pool 100 feet from the windmill, and is forced through 300 feet of 3-inch pipe into an earthen tank 50 by 100 feet, along the track of the Gulf, Colorado and Santa Fe Railroad. The water is elevated 14 feet. Five and a half acres of garden are irrigated. A ready market is found for all vegetables raised.

BURNET COUNTY.

There are three small systems in Burnet County, two from springs and one from the Colorado River. The latter receives its water from the dam of the Tanner Brothers, at Bluffton, and 30 acres are irrigated from this plant. Ten miles west of Burnet, Mr. Williams irrigates 15 acres in a truck garden, the water being obtained from a spring. A similar plant is located 10 miles south, at Marble Falls.

WILLIAMSON COUNTY.

There are a few small patches irrigated in the western and central part, but these consist of only a few acres. Early in 1902 H. T. Sterns installed a pumping plant 5 miles north of Taylor to irrigate ordinary crops. The water is derived from San Gabriel River by means of a 13-horsepower Charter gasoline engine operating a 3-inch Van Wie centrifugal pump. The dry-land corn around Taylor was burned up by the drought of 1902, and, as in the other central portion of Texas, it was cut for fodder. However, the irrigated corn of Mr. Stern afforded a severe contrast to the dry-land corn of his neighbors; while theirs was virtually burned up, his was as abundant as that grown on the best black land. The soil irrigated here is in the black waxy strip, which is known as the richest lands in Texas.

The few small systems referred to above are located along the San Gabriel and derive their water from springs. The plant of H. E. Townes is 8 miles west of Georgetown, and he irrigates 15 acres in tomatoes, sweet potatoes, beans, etc., from the old Knight spring. John Ischy, 4 miles west of Georgetown, irrigates a truck garden of 7 acres from the old Harper spring; while the plant of W. H. Donathan, 3 miles west of Georgetown, on the Middle Gabriel, irrigates his truck farm from a spring, in two levels, the lowest being irrigated from the ditches that lead from the spring, and the upper by means of a windmill that raises the water 3½ feet.

MILAM COUNTY.

Near Cameron, Milam County, five pumping plants were installed somewhat late in the season of 1902. Four of these take their water from Little River and the other from a spring. The plant of McLane & Crain is 2 miles southwest of Cameron, on the southeast bank of Little River, and consists of a 100-horsepower boiler, a 75-horsepower engine, and an 8-inch Van Wie pump working against a lift of 27 feet. The farm consists of the rich black shell bottom lands, with an admixture of sand near the river banks. The San Antonio and Aransas Pass Railway passes through this farm on a high trestlework. The cotton and corn had just been watered when the August floods completely submerged a large part of the crop, killing corn and cotton and making the season's work a complete loss. The plant of J. M. Crain consists of a 10-horsepower engine and a 3-inch centrifugal pump working against a lift of 26 feet. However, no results were obtained, on account of the overflow mentioned above. The island farm of John B. McLane lies almost south of Cameron, on the south side of Little River, and its topography is such that the ditches have a good fall as they leave the river bank. A levee along the river bank above the pumping plant should be constructed to protect the lands from destructive overflows of the river. The present plant consists of a 20-horsepower engine which operates a 5-inch Van Wie centrifugal pump against a lift of 27 feet. There are 175 acres in the farm, and it is intended to add heavier machinery in order to increase the acreage. Just west of the city waterworks plant, on the north bank of the river, L. F. Blanchard has an irrigated truck garden of 20 acres. The water is obtained from the river by means of a 15-horsepower stationary steam engine which operates a 4-inch centrifugal pump. The land is very rich, and two crops are readily raised each season. The 6-acre truck garden of S. J. Brooks is a mile west of Cameron, and is irrigated from a reservoir directly. The water from a spring is piped to a fish pond, from which it is pumped into the ditches. The plant consists of a 2.5-horsepower Weber gasoline engine which operates a 2-inch rotary pump against a lift of 6 feet. The land irrigated was formerly an old quagmire.

STAKED PLAINS.

The Staked Plains is a great plateau, about 36,000 square miles in extent, with an almost flat surface which gradually rises from an elevation of 3,000 feet to 4,500 feet above sea level. Flowing water, except from a few springs, is almost unknown. The soil is of such a character that it readily absorbs the rain that falls upon it, which percolates downward and is reached in wells from 40 to 200 feet in depth. Many of these wells are capable of furnishing a supply almost inexhaustible to ordinary means of pumping. The soil is often too dry to be successfully cultivated without irrigation, which can be practiced only by means of water raised by pumps. Pumping, however, is most easily accomplished by means of windmills, which are remarkably successful in this region, owing to the almost constant winds which sweep across the plains. Windmills have been used for many years to furnish water for stock, and they have been tried successfully on a small scale for irrigation. The settlers of the plains have learned to appreciate the value of devices of this character for raising water. Reservoirs or tanks are almost always used in connection with the mills. The sides and bottoms of these are made impervious by turning in a little water and puddling the soil by driving horses or cattle about in it for a day or more.

Morrison system.—About the center of the Llano Estacado or Staked Plains, in Hale County, T. W. Morrison owns a plant consisting of two Aermotors, 8 and 12 feet in diameter, respectively, pumping from wells 50 feet deep, with water 20 feet below the surface. Each windmill lifts the water 35 feet. One wheel is used for supplying the residence; the other pumps into a reservoir 125 feet long, 100 feet wide, and 4 feet deep, and irrigates 10 acres, besides furnishing water for the stock. These wheels have been in use since 1891.

Wayland and Herbert systems.—J. H. Wayland, of the same county, has three Aermotors pumping from wells 35 to 60 feet deep into a reservoir 300 feet long, 75 feet wide, and 6 feet deep, irrigating 10 acres in 1901. The total cost of wells, pumps, wheels, and reservoir was $505. The total cost of the plant, which must include land and fencing, is given as $1,000. W. P. Herbert also irrigates 5 acres, and C. E. McClelland states that there are at least 50 families in Hale County prepared to irrigate by windmills from 5 to 20 acres if the season renders irrigation necessary, but for the last two years the seasons have been so good that irrigation has not been practiced.

SYSTEMS NORTH OF TEXAS PACIFIC RAILROAD.

There are hundreds of windmill plants north of the Texas Pacific Railroad. In the counties of Haskell, Shackelford, and Young, in fact in nearly all the counties east of the one hundred and first merid-

ian, there are small garden patches, varying in size from one-sixth to three-fourths of an acre, irrigated by windmills. Fifty replies to letters sent out by the writer have not shown, with the exception referred to in these notes, a windmill plant that irrigated more than a half acre. Two windmill plants of Haskell County (those of W. H. Parsons and H. H. Nesbett) are typical of them all.

Parsons and Nesbett systems.—The plant of W. H. Parsons consists of a Dandy windmill 4 feet in diameter, pumping from a well and irrigating 1 acre. The plant of H. H. Nesbett consists of an Aermotor 10 feet in diameter and a 4-foot well 38 feet deep; depth to water, 31 feet. This wheel irrigates 3 acres of black, sandy soil.

Reynolds Land and Cattle Company.—The Reynolds Land and Cattle Company, near Channing, Hartley County, irrigates 40 acres from a spring. The principal crop raised is alfalfa, but a small orchard of fruit trees and a garden are also irrigated. The orchard consists of apples, peaches, pears, plums, and grapes. The underground water supply in the neighborhood of this ranch has not proved sufficient to irrigate more than small gardens.

Rathjen system.—F. H. Rathjen, of Mobeetie, Wheeler County, irrigates 60 acres of corn and alfalfa, from Williams Creek, which is fed by springs. The creek is 5 miles long and there is sufficient water to feed the quarter-mile ditch. The soil irrigated is a red loam.

Kempner & Lasker system.—Messrs. Kempner & Lasker have constructed a dam across Holiday Creek, about 5½ miles south and 20 degrees west of Wichita Falls. It is of earth, 3,000 feet long, 35 feet high in the creek, 25 feet high for 1,100 feet, and about 9 feet high at the north end. There are two wings, one 5,100 feet long and the other about 700 feet long, making a total length of 8,800 feet, or 1⅔ miles, and containing 150,000 cubic yards of material. The watershed is estimated to be 150 square miles. The creek is generally dry, but sometimes has a large flood volume passing down to Wichita River. The reservoir formed has a capacity of 13,000 acre-feet and covers 2,050 acres. It is estimated that it will irrigate from 4,000 to 8,000 acres. Part of this dam was washed away in May, 1901, but it is stated that it can easily be repaired.

LIMESTONE AND COMANCHE COUNTIES.

Stubenrauch system.—At Mexia, in Limestone County, J. Stubenrauch has been very successful in the use of a small irrigation plant for fruits and vegetables. The plant consists of a dam across a ravine, catching the storm waters and forming a tank covering about an acre of ground. From this the water is lifted to a height of 25 feet, by an 8-foot windmill, into an earthen reservoir 50 feet long and 100 feet wide. The reservoir is now being enlarged, to have double its present capacity. The total cost of the system was $300, including 700 feet

of piping. Seven acres have been irrigated, but it is estimated that 15 acres could be watered. Mr. Stubenrauch has put in another system, with a reservoir covering an acre of ground, the dam having a height of 5 feet above the outlet pipe. For filling the reservoir he uses a 12-foot wheel. He pumps from a storage tank made by damming a ravine. The dam on top is fully 10 feet wide, and both the reservoir and the storage tank hold water like a jug. The total cost, including 600 feet of 2½-inch pipe for discharging water into the reservoir, was $485.

Mr. Stubenrauch says:

For the gardener or fruit farmer there is no investment bringing in larger returns than an irrigation plant similar to what we have here. In the very driest season 300 bushels of sweet potatoes to the acre are easily grown, which can be disposed of during August and September at one's own prices. In 1899 there were grown some of the finest cauliflowers ever produced. Dozens of heads weighed over 6 pounds each. Have irrigated fruit only the past season (1900). Five acres irrigated as a truck farm near a good market are worth more to the owner than are 75 acres without, of similar land for the same purpose.

Lee system.—One and one-half miles from the town of Comanche W. T. Lee irrigates 5 acres from an 8-inch well 95 feet deep. The water is pumped by a windmill into a circular reservoir 100 feet in diameter and 6 feet deep. This reservoir was formed on a knoll, by scraping the earth from the central space into the leveed embankments. From the reservoir the water is conducted in different directions by 3-inch pipes and by ditches. The crops raised are chiefly garden vegetables and such fruits as pears, peaches, apricots, grapes, and blackberries.

WACO AND VICINITY.

In the suburbs of Waco, on both sides of Brazos River, pump irrigation has proved a paying investment. This is well established, not only by the data furnished, but by the fact that many are enlarging their plants and adding better machinery.

Plants east of Waco.—Two miles east of the city there is a cluster of a half dozen plants, all doing a successful business. E. Pordo has a surface well 19 feet deep and 6 feet in diameter, walled with brick. Ordinarily the water stands 3 feet in the well. A small centrifugal pump, having 2-inch discharge pipe, rests on the well covering and is operated by a 4-horsepower gas engine of local make. The head is 23 feet, into a flume 8 inches by 6 inches and 125 feet long, which empties into an earthen tank 60 feet by 60 feet on the inside. The system is reenforced by two Kirkwood windmills, which pump into elevated wooden tanks of 5,000 gallons capacity each. The windmills are 100 and 200 feet northeast of the tank, and each pumps out of a well of the same depth as the one just described. With good winds the windmills will supply sufficient water to irrigate the 3 acres. Adjoining the plant of Pordo is that of Robert Etheson, in all respects sim-

ilar to that of the former. The plant of Charles Myers consists of a 4-horsepower Lambert gas engine operating a plunger pump. The well is 32 feet deep, and the lift from the water to the flume is 38 feet. The water is pumped into a wooden tank of 6,300 gallons capacity, from which it is distributed to the garden through four outlet pipes 1½ inches in diameter. Instead of conveying the water to the different sections of land by ditches, a system of 1½-inch pipes is used. The land is watered from the pipes by means of a hose, or simply by removing the cap of the hydrant. It costs 65 cents a day to operate the engine for twelve hours. The soil is black loam, slightly impregnated with sand. The plant was first used in 1894. Ten acres are irrigated, although double that amount could be irrigated by the engine and the auxiliary windmill. Near the plant of Mr. Myers, Fred Stalte irrigates 4 acres by the use of a small gasoline engine and a windmill.

Etheson system.—One mile north of the foregoing cluster of plants, near Brazos River, A. Etheson irrigates 12 acres by the use of a gas engine pumping from a surface well.

Dismukes system.—In East Waco Ed E. Dismukes irrigates 16 acres with a 6-horsepower gasoline engine and a cylinder pump. At present the water is pumped out of a 6-inch pipe driven into 12 feet of water. The well which formerly existed was filled up and the 6-inch pipe substituted for it. The pipe is screened to prevent clogging by the sand. The suction pipe is 2 inches in diameter and the lift 9 feet. The water is pumped into a tank 30 feet by 120 feet by 5 feet deep, from which it is distributed.

Faulkner system.—About 1½ miles north of Waco is the fruit farm and garden of C. Faulkner, a tract containing about 400 acres. Of this about 350 acres are planted in fruit (pears, peaches, Burbank plums, apples, and blackberries), and about 30 or 40 acres form a garden in which vegetables, strawberries, and market produce are grown. The garden tract and a portion of that containing fruit trees (the late fruits) are irrigated from reservoirs or tanks on the highest points of the field, the water being supplied by an artesian well. The tanks are five in number, and consist of four levees thrown up to form a rectangular or roughly circular basin in which the water rises to a sufficient height to be conducted by gravity through pipes and ditches to all parts of the field. One of the tanks covers about 4½ acres and has an average depth of water of 8 feet. Two of them are about 120 feet by 150 feet and average 6 feet depth of water; the remaining two are smaller. The well was sunk in 1898, is 1,850 feet deep, has a 16-inch casing for about 20 feet from the ground surface, and a 6-inch delivery pipe. The water has a temperature of about 100° F., and is under a good pressure. It leaves a slight white deposit on the ground irrigated—so slight that it appears more like white frost than anything else—which, it is said, does not in any way injure the vegetation. The water is conducted from the tanks in ditches (piped under

the roads), and is distributed by side ditches and furrows. The average yield of pear trees is about 10 bushels, of peach trees about 5 bushels, and of Burbank plums (the only kind grown) 5 bushels. Apple trees have not yet begun to bear.

RICE IRRIGATION SYSTEMS.

GENERAL FEATURES.

The rice belt of Texas (fig. 18) extends from Sabine County, on Sabine River, to the Rio Grande, and at present includes two well-developed zones (the Beaumont and the Colorado Valley), which raise 75 per cent of the rice grown in the State, and several detached areas that are sure, with good management, to be the forerunners of extended systems in their respective localities.

In the Beaumont section the land is a level prairie, which heretofore has cut very little figure as an industrial factor. It is very flat, some of it having a slope of only 1 foot in 5,000 feet, and generally requires small levees and low lifts at the pumps. This flat section extends along the coast from Sabine River to the Rio Grande. The 250-foot contour above sea level is from 50 to 125 miles from the Gulf, while the strip 20 to 30 miles wide along the shore rises only a few feet above sea level.

In addition to this coastal belt the rice section has since 1897 been rapidly spreading back from the coast until it has reached Cuero, Fayetteville, and Hempstead on the west. In the flat sections the water is often obtained from bayous, and is frequently so impregnated with salt sea water that injury to the rice occurs. Rice must have an abundant supply of fresh water and a soil that is rich enough to nourish the plants and compact enough to hold the water, and it is being successfully grown in Texas wherever these factors are grouped, and where they do not exist naturally money and brains are grouping them with a twentieth-century effectiveness. No longer is the rice belt restricted to the old bayou country, but along the Brazos, the Colorado, the Guadalupe, and the Rio Grande more than 100 miles from the coast a high-grade rice is grown.

In addition, the irrigation of rice from wells will certainly prove of greater benefit to the Texas farmers than all of the big irrigation plants combined. The latter method of irrigation is in its infancy, but it is certain to become the chief factor in rice production in the State. The plant of George Vick, 2 miles east of Eagle Lake, is but the pioneer of many that will become established when the small farmer can, with a nominal outlay, convert his flat lands into a successful rice farm. A well 12 feet in diameter and 34 feet deep (7 feet of water), a traction engine to supply power, a submerged pump, an open box for a flume, a canal easily constructed—total cost $2,200—constitute Mr. Vick's equipment. With this 125 acres of excellent rice were

raised in 1900. This plant is now owned by Hudson & Ayres, and is referred to later in these pages.

The rice land is laid off in sections or "cuts" so that the extreme difference in elevation will not exceed 6 inches. The size of the cuts varies with the character of the topography. A cut is surrounded by levees or dikes, to hold the water, and it may be that a hillock or hole

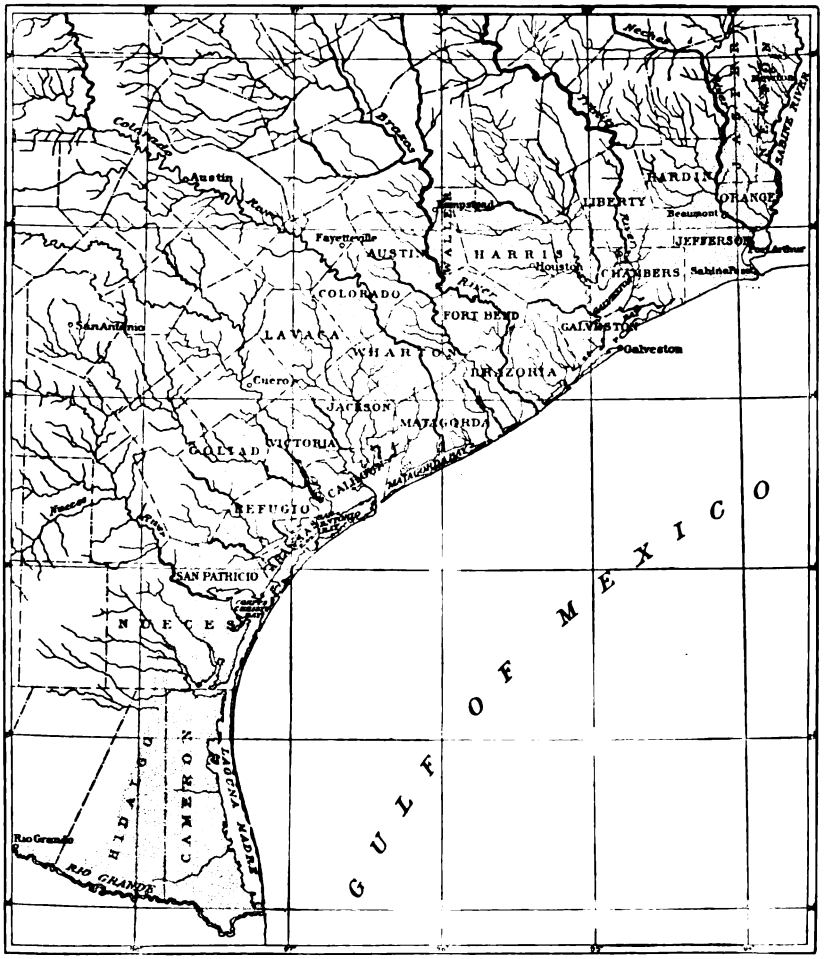

FIG. 18.—Map showing rice belt of Texas.

will occur in a cut. These can be ignored, however, for rice produces until time and the flow will level the one or fill the other. The water is pumped to the land by steam power, water power, or windmills, by far the greatest part of the work in Texas being done by steam.

From the best information obtainable in western Louisiana and eastern Texas it seems to be the consensus of opinion that it requires 9 gallons of water a minute for each acre of rice, or 1 second-foot to

each 50 acres. In the Beaumont section the rainfall often reduces the pumping considerably. During 1900, a wet year, some pumps were operated only four days. But a dry season will require the pumps to furnish the entire 9 gallons a minute for each acre, and it is not good engineering to estimate on less than that quantity, which is equivalent to 12,960 gallons per twenty-four hours per acre. If x is the number of acres to be irrigated and y the lift in feet, the weight of water to be supplied each second is $1.25\,x$ pounds, and the work done each second in pumping this amount is $1.25\,xy$ foot-pounds. The theoretic horsepower required would therefore be $\frac{xy}{440}$.

Thus for $x = 1{,}000$ acres and for a lift of $y = 22$ feet an engine exerting 50 absolute horsepower would be required. The estimated

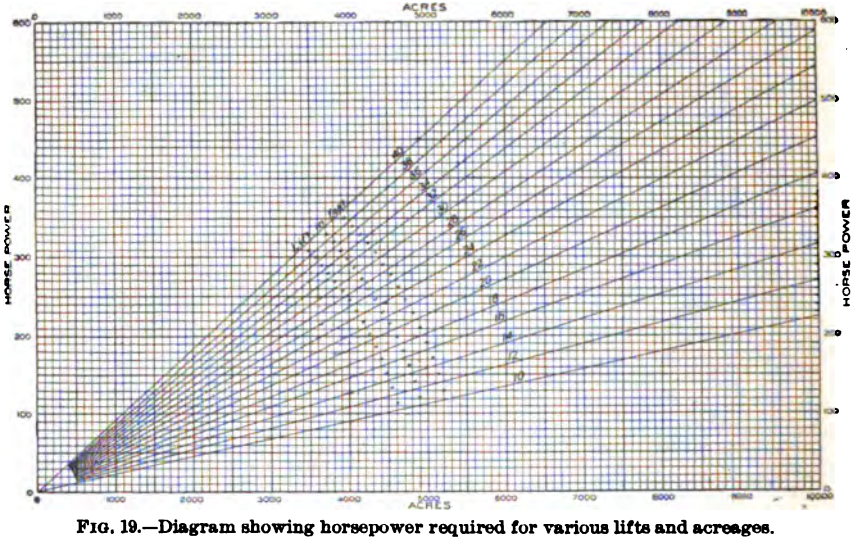

FIG. 19.—Diagram showing horsepower required for various lifts and acreages.

or claimed horsepowers of engines should be tested or reduced by a substantial fraction if disappointment in the capacity would be avoided.

By the aid of fig. 19 a person can at a glance determine the horsepower required to irrigate a tract of land. Given the lift and the number of acres to be irrigated, to find the horsepower of the engine first find the lift on the sloping lines (say 24 feet) and follow that line to the vertical line which corresponds with the number of acres to be irrigated (say 1,100), then follow the intersecting horizontal line to the left and read off the horsepower required—in this case 48—but in order to insure a safe margin an engine of 60 horsepower should be procured, and if the horsepower of the engine is based on the claims of agents a still larger margin should be allowed.

For some plants, owing to the contour of the ground, more than one lift is required, and more than one pumping station is necessary, the

pumping capacity of each station being the same, but the machinery in one station being heavier than that in the others, depending on the lift.

By means of flumes the water is led from the pumps to the canals, and from the main canals is turned into the laterals from which it is distributed over the land. The main canals are usually very wide, being in most cases intended to act as reservoirs.

The first experiments with growing rice in Texas were in 1862, the farmers depending on the rainfall to furnish the water. But this trusting to Providence in the matter of rice cultivation did not pay, and to insure success pump irrigation was resorted to. The culture of rice by irrigation began about 1893. Prior to that time it had been grown in only a small way in ponds and marshes for home use. The method of growing rice on a large scale by irrigation and with improved machinery is comparatively new, and is peculiar to the Southwest. Unlike Georgia and the Carolinas, where rice is still grown in the old way, the rice being planted in rows, the field flooded, and the water drawn off several times during the growing season, in Texas rice is sowed on comparatively high land with drills or broadcast, is cut with self-binders, and is thrashed from the shock or stacked, to suit the convenience of the farmer. The same kind of machinery is used in raising, harvesting, and thrashing rice that is used with other small grain, the only difference in the cultivation being that rice lands are flooded after the rice is up to a height of from 3 to 6 inches. The water kills the grass and weeds and causes the rice to grow rapidly.

In from ten to twenty days (depending on the grower and the nature of the soil before harvest) the levees on the lower side are opened and the water is drawn off by means of the ditches made in throwing up the levees. For some plants this drainage requires more engineering skill in the arrangement of the levees than in making them fulfill all the requirements for feeding the land with water. In Texas the practice is to sow the rice any time from April 15 to June 15. It is kept flooded from ninety to one hundred and ten days, one hundred days being the average. From 1¼ to 1¾ bushels are sown to the acre. The land is plowed and harrowed and prepared as for wheat. The outfit or equipment varies with the acreage. After the rice is planted and the water is turned on eternal vigilance is necessary to keep canals and ditches in order, to prevent breaks and the consequent waste of water and drowning out of part of the crop. It is by no means an easy crop to manage. From the first flooding until harvesting the work is a muddy history of patience. Just before the crop ripens the water is drawn off to permit the ground to harden enough to bear the binder. If the rains set in at this critical time it entails additional expense and trouble to save the crop. In this respect the rice farmers away from the coast have an immense advantage, for

there the rainfall aids during the flooding period and does not jeopardize the crop during the time of harvest. While the cost of pumping is more in the western part of the rice belt, the surety of an undamaged product will always overbalance the additional expense.

BEAUMONT SECTION.

The irrigation systems in the Beaumont section, which comprises the counties of Jefferson, Orange, Liberty, and Chambers, are shown in the maps forming figs. 20 and 21, and are described on the following pages.

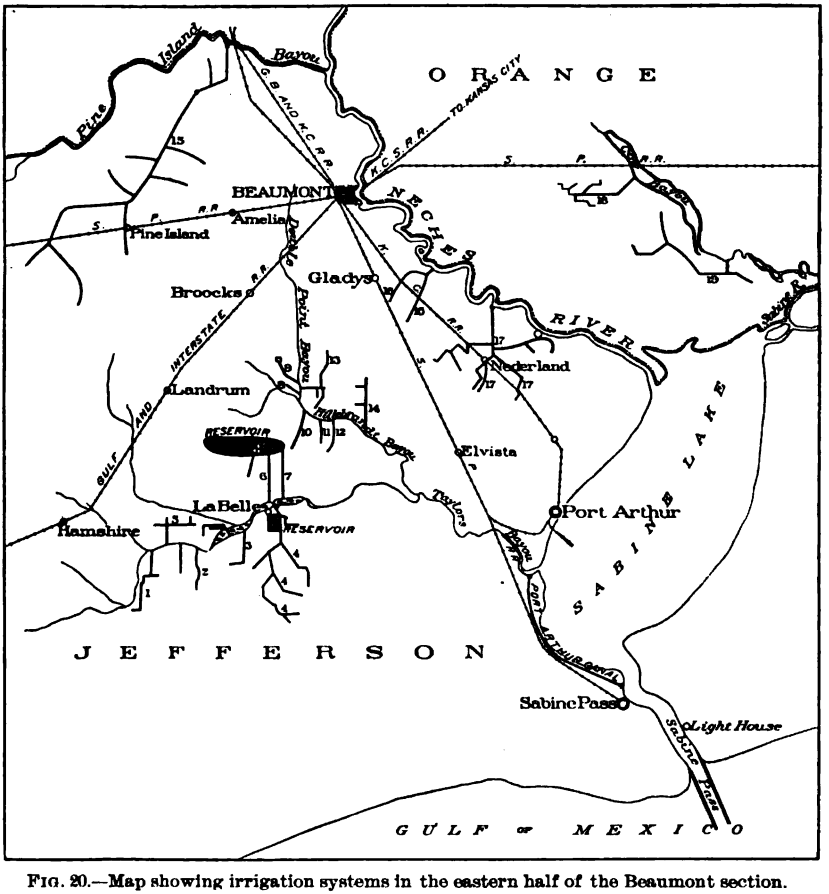

FIG. 20.—Map showing irrigation systems in the eastern half of the Beaumont section.

1. George Gill.
2. J. H. Garland.
3. J. C. Ward.
4. Jefferson County Rice Company.
5. J. H. Hoopes.
6. Lovell Brothers.
7 Ed. Moore.
8. Gulf Rice Growing Company.
9. Southern Rice and Trust Company.
10. C. A. Place.
11. Mr. Davis.
12. Schumacher & Fox.
13. Cameron & McClure.
14. Viterbo Brothers.
15. Beaumont Rice Company.
16. McFadden & Wiess Company.
17. Port Arthur Rice Company.
18. Des Moines Irrigation Company.
19. Cow Bayou Canal and Irrigation Company.

JEFFERSON COUNTY.

Of all the counties of Texas in which the people have tried rice growing by means of irrigation, Jefferson County undoubtedly stands first in extent of acreage and in successful cultivation.

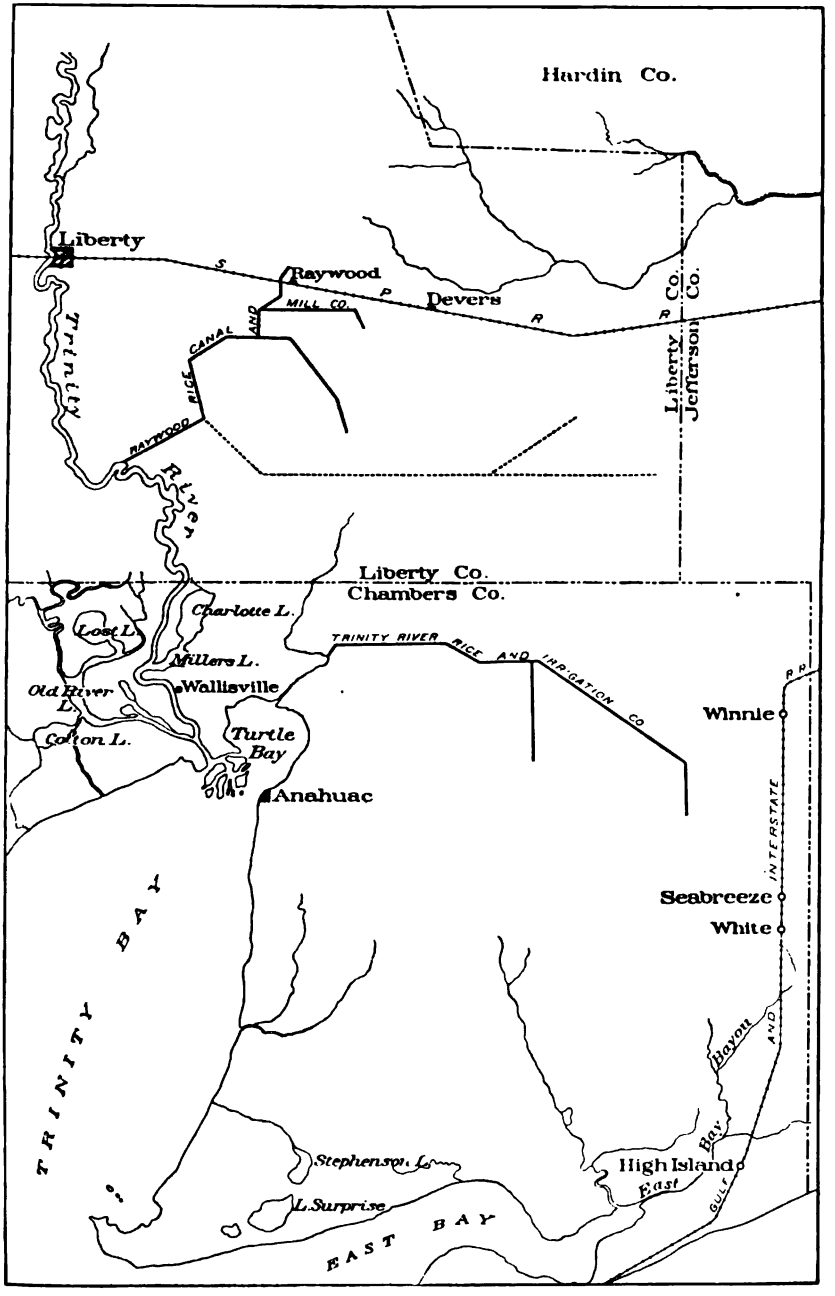

FIG. 21.—Map showing irrigation systems in the western half of the Beaumont section.

The rice farms and plantations are in two general districts, one in the valleys of Taylors and Hillebrandt bayous, above their junction in the southern part of the county, and the other along the valleys of Neches River and the Pine Island Bayou. All of the farms owned and operated by individuals are on Taylors and Hillebrandt bayous. There are also in the county five rice-growing companies, known as the Beaumont Rice Company, the McFadden & Wiess Company, the Port Arthur Rice Company, the Jefferson County Rice Company, the Southern Rice and Trust Company, and the Gulf Rice Growing Company.

The following is a list of the rice irrigators in the county. arranged in order going downstream:

Rice irrigators in Jefferson County.

Name.	Stream.	Acres irrigated.	
		1900.	1902.
George Gill	Taylors Bayou (S.)	600	1,500
J. G. Garland	do		750
J. C. Ward	do	900	700
Jefferson County Rice Co	do	1,800	2,300
J. H. Hoopes	Taylors Bayou (N.)		600
Bigham Bros	do	1,200	400
P. S. Lovell	do	850	760
Ed. Moore	do	100	60
Gulf Rice Growing Co	Hillebrandt Bayou (SW.)	150	300
C. A. Place	do	450	500
Southern Rice and Trust Co	Hillebrandt Bayou (NE.)	900	900
Cameron & McClure	do	550	680
Viterbo Bros	do	600	950
Beaumont Rice Co	Pine Island Bayou	12,000	15,000
McFadden & Wiess Co	Neches River	None.	9,000
Port Arthur Rice Co	do	4,000	8,500
	Wells		1,480
Total			44,380

General descriptions of the plants are given on the following pages; also, where obtainable, the opinions of the growers in reference to time of sowing, disposal of the straw, nature of the land, and other convictions drawn from experience.

The dry season of 1902 caused the impregnation of Taylors and Hillebrandt bayous with salt water, and the 10,000 acres of rice on these bayous suffered accordingly. It is claimed that the ship canal from Sabine Pass to Taylors Bayou has increased the danger from salt water in these bayous, and attention is here called to the necessity of a dam across Taylors Bayou at the mouth to keep back salt water.

TAYLORS BAYOU.

Gill system.—George Gill's farm is the westernmost irrigating from Taylors Bayou. The soil is of clay, with no sand, and is very hard to plow. Mr. Gill uses the drill and also sows broadcast, but he recommends the former method. His yield has averaged 7 sacks an acre. There are two complete pumping plants on the farm. One consists of an Ivens rotary pump, having a capacity of 9,000 gallons a minute

against a lift of 12½ feet, and a Skinner engine and 80-horsepower boiler made by the Columbia Boiler Works. The other plant consists of a Menge pump, having a capacity of 300,000 gallons an hour against a lift of 3 feet, and a Taylor compound engine and a boiler of the same make and steaming capacity as that of the other plant. The flume is 6 feet wide, 2 feet deep, and 24 feet long. The main canal is 60 feet wide and 3 miles long, with several laterals. The total cost of the equipment was about $5,000. Mr. Gill irrigated 400 acres in 1899, 600 acres in 1900, and 900 acres in 1901. For all purposes he recommends low-speed engines (though both of his engines are high speed) and slow-speed pumps, as they seem to give better satisfaction.

Garland system.—J. G. Garland's farm lies along Taylors Bayou, about 20 miles southwest of Beaumont. The soil is very sticky, although it works well when dry. Mr. Garland sows either with a drill or broadcast, from March 20 to about June 10, and uses the ordinary binder in reaping. While thrashing he saves sufficient straw for feeding purposes and burns the surplus. For the first rice sown irrigation is begun about May 20, depending on the season, and is continued until almost time of harvesting. The yield from this land has been 10 barrels to the acre, the price of seed from $3 to $5 a barrel.

He uses one pump, of the Menge pattern (manufactured by the estate of Joseph Menge at New Orleans, La.), having a capacity of 15,000 gallons a minute (33 second-feet) under a lift of 8 feet. A 75-horsepower Skinner engine drives the pump by means of rope transmission. The boiler used for steaming has a capacity of 90 horsepower, and was manufactured by the Union Iron Works and Skinner Engine Works, of Erie, Pa. There are two laterals—one a half mile long and the other three-fourths of a mile long. The total cost of the plant was about $2,700. With this equipment Mr. Garland irrigated 600 acres in 1899 and 750 acres in 1902.

Ward system.—The farm of J. C. Ward is the next one on the south side of Taylors Bayou. The soil is generally sandy, with a good clay foundation near the surface of the ground. His methods of sowing, cultivating, and reaping are as follows: Beginning about March 1, he continues to sow until the last of May, using either the drill or sowing broadcast. Irrigation is begun about the 1st of June, though this depends upon the weather. When matured, the rice is harvested with binders, and then thrashed. All the straw needed for feeding purposes is saved, the remainder is usually burned. The average yield has been 10 barrels (35 bushels) an acre, for which Mr. Ward has received $3 a barrel. There are two complete pumping plants on the farm. The pump at the larger station is of the Menge type, with a capacity of 720,000 gallons an hour (27 second-feet). A 100-horsepower Atlas engine is installed, with only an 80-horsepower Atlas boiler. At the other plant there is a 500,000-gallon Menge pump, an

engine of local make, and only a 30-horsepower boiler. The lift in each case is 9 feet. The larger plant cost $5,000, the smaller only $1,500. The flume is 60 feet long, 12 feet wide, and 4 feet deep; the box part is constructed of 2-inch planking. The main canal is from 60 to 40 feet wide and 2 miles long, and has several large laterals

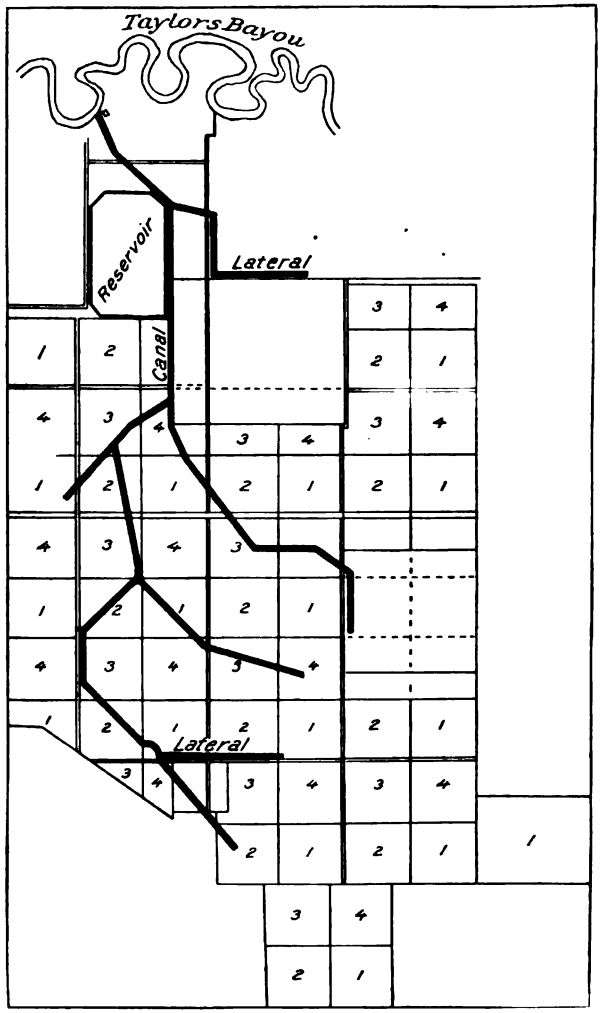

FIG. 22.—Map of Jefferson County Rice Company's farm, showing irrigation canals.

branching off. Mr. Ward irrigated about 400 acres in 1899 and 900 acres in 1900, but the plant is now leased to Bigham Brothers.

Jefferson County Rice Company system.—The farm of the Jefferson County Rice Company is 17 miles from Beaumont, and is the last one on the south side of Taylors Bayou, all the land below being marshy and subject to overflow from salt water. Two pumps, one 22-inch Marri and one 15-inch Ivens, of capacities of 20,000 and 7,500

A. PUMPING STATION OF JEFFERSON COUNTY RICE COMPANY.

B. RICE THRESHER AT WORK ON PORT ARTHUR IRRIGATION COMPANY'S PLANTATION.

gallons a minute, respectively, raise the water from the bayou against a lift of 15.1 feet. The engines are of the Erie make, of capacities of 150 and 50 horsepower, respectively. The boiler is of the same make, and has a steaming capacity of 200 horsepower. The flume is 12 feet wide, 3 feet deep, and 180 feet long, and discharges into a canal 100 feet wide. The soil is a deep, black, sandy loam and has a clay subsoil. In 1899 it yielded 8 sacks to the acre. This farm has been irrigated six years. Fourteen hundred acres were planted in 1899, but the number was reduced to about 800 acres in 1900. In 1901 about 3,000 acres were irrigated. Pl. VII, *A*, is a view of the pumping station. The smaller pump was installed in 1896, the larger (a 150-horsepower) in 1898. The company owns 10,424 acres of land, which they have divided into quarter sections and thrown open to actual settlers. So far 3,800 acres have been sold to settlers, on the crop-payment plan, at from $20 to $25 an acre, one-half of the crop being given to the company until the land is paid for. The highest point on the farm is at the pumping station, and this enables the company to flood the whole tract without additional lifts by pumping. To insure a full supply, a reservoir covering 500 acres has been constructed, with an average depth of 4 feet and a capacity of 2,000 acre-feet, or 1,300,000 gallons. A map of this farm showing the irrigation canals is shown in fig. 22.

Hoopes system.—J. H. Hoopes's farm is in the lowlands made by Taylors and Hillebrandt bayous. Some of the soil is black and waxy, some is black loam, and some is sandy, but all has a clay subsoil. The yield has been from 8 to 12 sacks to the acre. A Menge pump, manufactured in New Orleans, with a capacity of 16,600 gallons a minute, furnishes the water. The pump works against an average lift of 10 feet, varying with the stage of the water. An Erie engine of 60 horsepower is used, and an Erie boiler of the same steaming capacity. The flume is 32 feet long, 9 feet wide, and 1 foot deep, constructed of 1-inch boards and lined with galvanized iron, which is an exception to the ordinary flume in this district. The main canal is 100 feet wide and 1 mile in length. Six hundred acres were planted in 1899, 400 acres in 1900, and 600 acres in 1902. The total cost of the plant was about $4,000.

Moore system.—Mr. Ed. Moore's farm is near the Hoopes farm. The soil is a mixture of clay and loam. The yield last year was below the average, being only from 6 to 8 sacks to the acre. He uses an Ivens centrifugal pump having a capacity of 200,000 gallons an hour against a lift of 17 feet. One 60-horsepower engine, of the Cleveland make, operates it, steam being supplied by a 75-horsepower boiler. The flume is 200 feet long, 3 feet wide, and 1 foot deep. The canal is from 15 to 30 feet wide and 2 miles in length. One hundred and fifty acres were irrigated in 1899, 100 acres in 1900, and 60 acres in 1902.

Bigham system.—The plant of Bigham Brothers is on the north

side of Taylors Bayou, near Labelle. It consists of two pumps having discharge penstock 2 by 3 feet. The lift of one pump is 8 feet, of the other pump 12 feet. The power is supplied by two engines of 40 and 80 horsepower, respectively. The water is raised into flumes 30 and 100 feet long, and these discharge into the main canals, which are a half mile and 3 miles long, respectively. There were 400 acres in rice in 1899, 1,200 acres in 1900, and 1,200 acres in 1901, notwithstanding the unusual severity of the latter season. The yield in 1900 was 8,000 sacks, commanding $3 a sack. The soil is a black loam, and is well suited to rice culture. This firm operates the J. C. Ward farm.

Lovell system.—The plant of the Lovell Brothers (Willard G. Lovell, manager) is on the north banks of Taylors Bayou. It consists of an Ivens pump having a 21-inch suction pipe and an 18-inch discharge pipe, and estimated to have a capacity of 18,000 gallons a minute (40 second-feet) under a maximum lift of 18 feet. The plant is run by a Houston, Stanwood & Gamble engine of 100 horsepower. With an engine efficiency of 75 per cent this can pump only 275 gallons a second, or 16,500 gallons a minute. The flume is 146 feet long, 10 feet wide, and 3 feet deep. The length of the main canal is 3½ miles, the width 50 feet. One mile of the laterals is 20 feet wide, 1½ miles are 15 feet wide, and a half mile of them is 10 feet wide. In 1899, 1,100 acres of rice were sown; in 1900, 850 acres; in 1901, 850 acres; and in 1902, 760 acres.

HILLEBRANDT BAYOU.

Southern Rice Company system.—The plant of the Southern Rice Company is the northernmost diverting water from Hillebrandt Bayou. It is about 12 miles south of Beaumont. The plant is equipped with Ivens pumps having 22-inch suction pipes and 21-inch discharge pipes, operated by a 100-horsepower Chandler & Taylor engine, estimated to have a capacity of 15,000 gallons a minute (33 second-feet) under a lift of 13 feet. With an engine efficiency of 70 per cent, 71 horsepower will do this work. The water is delivered by the pumps into a flume 150 feet long, 8½ feet wide, and 4 feet deep. The main canal is 1½ miles long and 75 feet wide, and delivers into laterals 12 feet wide. The soil is black, with a clay subsoil. Water was rented in 1899, when 200 acres of rice were sown, yielding 2,000 sacks, which sold for $2.70 a barrel. The amount sowed in 1900 was 900 acres, yielding 7,000 sacks, which sold for $3 a barrel. In 1902 about 960 acres were sown.

Gulf Rice Growing Company system.—The farm of the Gulf Rice Growing Company is 10 miles southwest of Beaumont on Hillebrandt Bayou. The lift is about 12 feet, and the water is pumped by a 90-horsepower engine. The soil is a clay loam, 300 acres of which, in rice, were irrigated in 1902.

Place system.—The plant of C. A. Place has one Morris pump

having 15-inch suction and 12-inch discharge, operated by a 25-horsepower Westinghouse "Junior" engine, having a maximum capacity of 10,000 gallons a minute (222 second-feet) against a lift of 12½ feet. The water is delivered into a flume 28 feet long, 4 feet wide, and 2 feet deep, which in turn delivers it into the canal, which is 1 mile long and 60 feet wide. The soil is clay and black loam, with a subsoil. Two hundred and fifty acres, in rice, were irrigated in 1899, 450 acres in 1900, and between 450 and 500 acres in 1901. The yield in 1900 was 3,400 sacks, commanding $3 a sack. The plant cost $2,500. Previous to 1899 other parties owning this farm had irrigated 125 acres.

Cameron & McClure system.—The rice plantation belonging to Messrs. Cameron & McClure is on both sides of Hillebrandt Bayou. The soil is light, but it has a fine clay subsoil which retains the water well. The rice is sown from March 25 to May 1, and if the season is not rainy irrigation is begun when the rice is about 6 inches high. The yield has been from 7 to 10 sacks to the acre, and the price received ranges from $1.25 to $3.40. The lower prices were received for rice of poor quality, much of it being damaged by what is termed "red rice." The reaping is done with the ordinary harvester and binder. The owners of the plantation have found that the straw makes very good hay.

Owing to the farm being on both sides of the bayou, there are two complete pumping plants. At one of the plants there is in use a 6-foot Menge pump, having a capacity of 12,000 gallons a minute (27 second-feet) against a head of 10½ feet. The engine is of the Skinner type, of a capacity of 75 horsepower, and receives steam from a 100-horsepower boiler. The other plant has a 12-inch pump of the Van Wie make, which has a capacity of 7,500 gallons a minute (17 second-feet) against a head of 10½ feet. This pump is run by a 40-horsepower Skinner engine which is supplied with steam by a 50-horsepower Van Wie boiler.

The flumes are 40 and 60 feet in length, 12 and 8 feet wide, and 12 inches deep. They are constructed of 4-inch by 4-inch timber in the bents, while the sides and bottoms are made of 12-inch planking.

Four hundred and fifty acres were irrigated during the year 1899, 550 acres in 1900, and 680 acres in 1902.

Viterbo Brothers system.—This system is 12 or 14 miles southwest of Beaumont. One Menge pump, costing $500 and having a capacity of 25,000 gallons a minute against a lift of 7 feet, is used. Two boilers, each of 50 horsepower, furnish the steam to a 75-horsepower engine. The canal is 40 feet wide and 2½ miles in length. A reservoir, covering an area of 225 acres and having a depth of 6 feet, holds the storage water. There are 1,000 acres leveed in, but not all of this is planted in rice. The yield on this land has been from 7 to 18 sacks to the acre. Six hundred acres were sown in 1899, 600 acres in 1900, 700 acres in 1901, and 950 acres in 1902.

PINE ISLAND BAYOU.

Beaumont Irrigation Company system.—This company has been operating the largest rice plantation in Texas. It is in the northern part of Jefferson County, lying along the south side of the Pine Island Bayou. There are two lifts. The first one is at the crossing of the

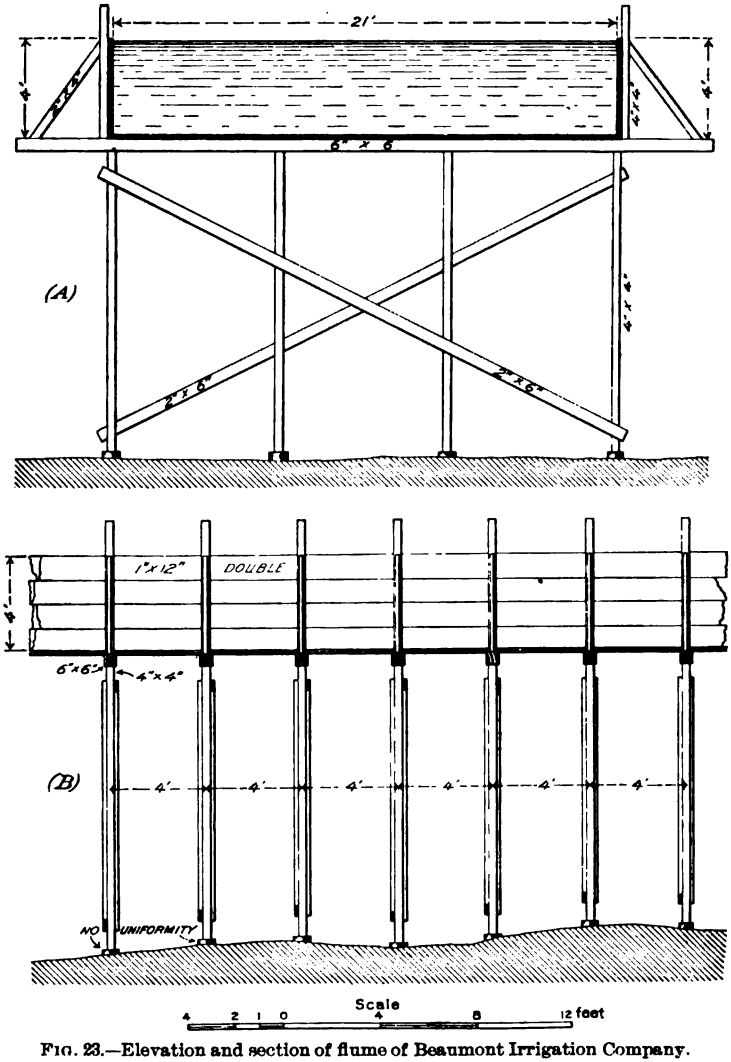

FIG. 23.—Elevation and section of flume of Beaumont Irrigation Company.

Southern Pacific Railroad, and raises the water from Pine Island Bayou. Until 1890 there were at this lift two Connersville compound blower pumps, each having a capacity of 25,000 gallons a minute. To each of these pumps was attached one Hamilton-Corliss engine of 250 horsepower, steam being supplied by 300-horsepower boilers. In 1900

another pump of the same capacity was installed, with a corresponding engine and boiler. The pumps work against a lift of 31 feet, and have always given satisfaction. They are 15 feet above the water in the bayou, and force the water 16 feet into the flume. Wood is used altogether for fuel. The flume, shown in elevation and section in fig. 23, is 4 feet deep, 21 feet wide, 1,500 feet long, and has a total fall of only 4 inches. The box part is constructed of 1-inch by 12-inch planks, the floor and sides being double planked, and all joints broken and tarred. The floor rests on 6-inch by 6-inch sills, which are supported by four 6-inch by 6-inch uprights. The distance between the bents is 4 feet. The canal is 150 feet wide.

For 3 or 4 miles from this lift the land is covered with pine growth and is somewhat broken. The portion covered with timber would be expensive to prepare for cultivation, and that broken could not be irrigated. So the water has to be carried to almost the second lift before the farms are reached. The whole plantation is on the prairie, the land gradually rising from the first lift. It is about 5 miles from the first lift to the second lift, where the water is raised 11 feet. The pumps here, both the two old ones and the new one, have the same capacity and are of the same make as those at the first plant, but owing to the low lift they are of lighter construction. The engines also are of the same make, and are of 150 horsepower each. The same may be said of the boilers, the steaming capacity of which is 200 horsepower. The flume is similar to the one at the first plant, but it is only about 200 feet long.

It is estimated that about $135,000 has been expended on this plantation. The company irrigated about 5,000 acres in 1899, a large part of which was rented to individuals. In 1900 12,000 acres were irrigated, 4,000 of which were cultivated by the company, the remainder being rented to 37 individuals. The custom of renting is to charge 2 sacks (162 pounds) an acre for water alone and 2 additional sacks where the company rents the land, making a total of 4 sacks an acre where both land and water are rented. The average yield on this plantation is about 10 sacks to the acre, though some of the tracts may run up as high as 20 sacks. The canals and laterals follow the general contour of the ground. Machinery has been added from time to time, till now (1902) the river plant has three 350-horsepower and two 250-horsepower engines and two 36-inch and two 48-inch Connersville and one 60-inch Roots pumps, while at the second lift there are two 200-horsepower and two 125-horsepower engines and two 36-inch Connersville and two 36-inch Morris pumps. In 1902 there were irrigated 14,615 acres.

NECHES RIVER.

Port Arthur Irrigation Company system.—This plantation is on Neches River, about 12 miles southeast of Beaumont and about the same distance northwest of Port Arthur. The pumping plant is on the banks of the river, from which the water is pumped, the lift being

21 feet. The plant has been in operation three years. Until the season of 1900 there was in use only one 18-inch Ivens pump, having a capacity of 18,000 gallons a minute. In 1900, however, two 24-inch Ivens pumps, each having a capacity of 24,000 gallons a minute, were installed. The other operating machinery, including that installed with the new pumps, consists of two 125-horsepower boilers, four 100-horsepower boilers, one Chandler & Taylor engine, and one new Corliss engine of 350 horsepower.

The flume was formerly about 100 feet long, 20 feet wide, and 4 feet deep, but in 1900 this was increased in width to about 60 feet. The main canal is 100 feet wide and has very high levees, but it is doubtful whether this is the most economical form of construction. One thousand seven hundred acres were irrigated in 1899, 4,000 acres in 1900, and 7,000 acres in 1901. A charge of 2 sacks is made for water and 2 sacks for land rented. Pl. VII, *B*, is a view of a rice thresher at work on this farm. The yield in 1899 was about 14 sacks an acre. The rice grows very rank, varying in height from 5 to 7 feet. Some of the straw was baled and found to make very good hay; the remainder was burned. All of the land on which this rice is grown is black and sticky. (See map, fig. 20, for plot of the main canal and laterals.) This company irrigated 8,500 acres in 1902.

McFadden & Wiess system.—This plant is on the western bank of Neches River, or rather on the edge of the marsh that lies between the river and the rice lands, about 7 miles southeast of Beaumont. The water is conveyed from the river to the plant by a canal dredged out of the marsh. Its length is 2,000 feet, width 40 feet, and depth 6 feet. The plant was located on the edge of the marsh, a foundation being obtained by driving piles 3 feet apart under the power and pump house. On top of the piles several courses of grillage work were laid, and this was capped by a cement foundation for the machinery.

There are two Connersville rotary cycloidal pumps, with suction pipes 2½ by 6 feet and discharge pipes 4 feet in diameter. The pumps are run by two Hamilton-Corliss compound condensing engines of 250 horsepower each. The capacity of the plant is estimated at 70,000 gallons a minute (156 second-feet) under the lift of 22 feet, which would require an efficiency of 78 per cent in the machinery. The main canal is 6 miles long, 100 feet wide, and 2½ feet deep. The plant cost $65,000, the machinery costing $40,000. Four thousand acres of rice were irrigated in 1901, and 9,000 acres in 1902.

WELLS.

In addition to the canal plants in Jefferson County there are a number of plants that derive their water from wells. These are located near Hamshire and China. The well of George J. McManus, near Hamshire, will serve as a type of those in this section. There are two wells 40 feet apart, connected in the pit 22 feet deep. One is

81 feet deep; the other 180 feet. The water-bearing sand was found to be 72 feet thick, and the screw was put in in three lengths of 20 feet each. It consisted of an 8-inch pipe with three-fourths inch holes bored with 1¼-inch clear space between them. The pipe was then wrapped with No. 16 wire, one-fifth of an inch apart, and on this was wrapped the copper gauze of mesh 60, 30, and 40 to an inch. The 6-inch Van Wie pump is operated by a 22-horsepower Gear-Scott steam engine, using Beaumont oil for fuel. From this plant 120 acres of rice were irrigated in 1902. In the same neighborhood H. C. Wheeler has a well plant that derives its water from flowing wells. At one of these wells it was 207 feet to the water-bearing sand that furnishes the supply. This is 43 feet in thickness, making the total depth of this well 250 feet. Near Hamshire the acreage from wells was: McManus, 120; Wheeler, 300; Heisig, 185; total, 605 acres.

The acreage around China from well plants was, Hal Aldridge, 125; J. W. Kirby, 200; Burrows, 200; Southwestern Company, 200; Spivy, 150; total, 875.

ORANGE COUNTY.

COW BAYOU.

Cow Bayou Canal and Irrigation Company system.—Rice irrigation has been conducted in Orange County for about ten years. In 1891 F. H. Catron installed a 50-horsepower engine to operate a Menge pump under a head of 8 feet, the plant being located on Cow Bayou, about 6 miles southwest of the town of Orange. The ditch was 1 mile long and 20 feet wide. The plant cost $6,500, the canals and laterals costing $5,000 and the engine and pumps $1,500. The capacity of this plant was 5,000 gallons a minute, or 11.11 second-feet. With an efficiency of 75 per cent for the engine the pumping of this amount of water requires only 14 horsepower. Six hundred acres of rice were irrigated in 1896. This system has passed into the control of the Cow Bayou Canal and Irrigation Company, which has remodeled the whole plant, removing the pump to a more advantageous location and installing one 250-horsepower Viker-Corliss engine having an 18-inch by 36-inch cylinder and operating two 18-inch Ivens double-suction latest improved pumps having a capacity of 30,000 gallons a minute (66.67 second-feet) against a lift of 14 feet. There are 5½ miles of main canal. (See fig. 20.) For the first 1.5 miles the width is 80 feet, for the next 1.5 miles it is 50 feet, and for the remainder of the distance it is 60 feet. The water is first pumped into a flume 20 feet wide, 4 feet deep, and 300 feet long. The cost of the plant, including engines, pumps, canals, laterals, flumes, etc., was $25,000. Three thousand acres were planted in rice in 1901.

Des Moines Rice Company system.—About 7 miles west of Orange and 4 miles from Terry is the plant of the Des Moines Rice Company, which consists of an Ivens pump having 21-inch discharge pipe, oper-

ated by a 125-horsepower Atlas engine, having a claimed capacity of 20,000 gallons a minute (44 second-feet) against the lift of 17 feet. This duty will require an efficiency of 68 per cent in the engine. Pine wood is used as fuel, and it takes about 5 cords each twelve hours. The flume is 200 feet long and 10 feet wide. The main canal is 3½ miles long and 100 feet wide, and there are 4 miles of branches varying in width from 20 to 50 feet. (See fig. 20.) The plant was installed in 1899, and 960 acres of rice were sowed that year, commanding a price of $3.25 a barrel of 162 pounds. In 1900, 1,400 acres were planted, and in 1901 about 1,600 acres. The soil is a black loam.

ADAMS BAYOU.

Orange County Rice Company system.—The plant of this company is on Adams Bayou, 4 miles from Orange. It consists of a 24-inch Ivens direct-connected pump and a 100-horsepower engine. Under a lift of 8 feet the plant has a capacity of 20,000 gallons a minute. In 1901 about 2,500 acres were irrigated, and 3,500 acres in 1902. The first lift is 16 feet, and the two pumping plants, 2 miles apart, when visited in August, 1902, had all the rice well watered, and the whole crop was healthy in appearance.

Clark system.—The Clark Canal Company (A. T. Chenault, manager) is north of Orange and takes its water from the east side of Adams Bayou, under a lift of 16 feet. The machinery consists of a 50-horsepower Morris steam pump, and 500 acres were planted in 1902.

Giles system.—The plant of Giles Brothers takes its water from Adams Bayou, on the west side, under a lift of 18½ feet. One 50-horsepower Ames engine operates the Menge pump, with a 4 by 4 penstock. In 1902 550 acres were planted.

Acreage in Orange County.—The acreage in Orange County is as follows: Cow Bayou Company, 4,500; Orange County Company, 3,500; Des Moines Company, 1,200; Samuel Wilson Company, 600; Clark Canal Company, 500; Giles Brothers, 550; total, 10,850 acres.

CHAMBERS COUNTY.

TURTLE BAYOU.

The Trinity River Rice and Irrigation Company take their water from Turtle Bayou and Trinity River, 22 miles south of Liberty. (See fig. 21.) The plant consists of four large pumps, having 24-inch suction and discharge pipes, and a capacity of 20,000 gallons a minute each, or a total of 80,000 gallons a minute (173 second-feet), against a lift of 32 feet. There are four 250-horsepower engines, exerting a total of 1,000 horsepower (estimated). However, with an efficiency of 70 per cent it requires only 781 horsepower to pump the estimated quantity. Three of the pumps should be able to do all of the work. There are three flumes of a total length of 2,400 feet, a width of 15 feet, and a depth of 40 inches and 16 miles of main canals 100 feet wide and 10 miles of laterals 40 feet wide. The plant cost $13,000, and in a dry

season can irrigate 9,600 acres of rice with the usual evaporation. In 1900, 6,000 acres of "Providence" rice were cultivated, producing 29,000 sacks, which brought $3 a barrel. A sack averages about 180 pounds, while a barrel is always 162 pounds. The company sowed 9,000 acres in 1902. Generally they sow during May and June, using about 60 pounds to the acre. Renters are charged one-fifth of the crop for water, one-fifth for land, and one-tenth for seed—i. e., the company furnishes land, seed, and water, and receives half of the crop.

LIBERTY COUNTY.

TRINITY RIVER.

The Raywood Rice Canal and Milling Company has one of the largest plants in Texas. It is on the east side of Trinity River in Liberty County (see fig. 21), and cost $200,000. It was not installed until the latter part of 1900, but owing to excessive rains the company raised a good average crop of "Providence" rice that year. There are 10 miles of main canal from 100 to 150 feet wide, and 25 miles of main laterals from 60 to 80 feet wide. There are three lifts aggregating 70 feet, with a pumping station at each lift. The pumps are of the Root rotary pattern. Those at the river station have an estimated capacity of 45,000 gallons a minute (100 second-feet) under 16 feet lift. The suction pipes are 3 by 8 feet. Four of the pumps have circular discharge pipes 5 feet in diameter; the other two have rectangular discharges 3 by 8 feet. The pumps at the river station are operated by two 475-horsepower Lane & Bodley engines. The second station is equipped with two 375-horsepower engines operating two Root rotary pumps under a lift of 24 feet. The third station has two 250-horsepower engines operating two pumps having 5-foot circular discharge and suction pipes. The head at the latter station is 30 feet.

The soil is a black loam. Six thousand acres were cultivated in 1900, producing 50,000 sacks, which sold for $3.25 a sack. In 1902 the company planted 15,000 acres. The rice is sowed by a drill or broadcasted in April, May, and June, 1½ bushels to the acre. The land is let out to renters on the one-half plan—i. e., one-fifth of the crop for land, one-fifth for water, and one-tenth for seed. In 1901 oil was used for fuel, the cost being about one-third that of coal.

WELLS.

Near Stilson, 32 miles east of Houston, on the Southern Pacific Railroad, Brown & Son have a rice plant, the water for which is obtained from an artesian well 405 feet deep. The pit is 17 feet deep. The first 280 feet are of 8¼-inch casing, the remainder of 5⅝-inch casing. A 22-horsepower Port Huron traction engine supplies the power required to operate the 6-inch Morris pump, which raises the water 12 feet into a flume. The land is composed of a black prairie soil. One hundred and sixteen acres were irrigated in 1901, producing 870 sacks of rice. In 1902 200 acres were planted.

N. B. Sapp has an 8-inch artesian well 380 feet deep. In boring

this well a cypress log was struck at a depth of 360 feet. The operating machinery consists of one 18-horsepower Foos gasoline engine and two 16-inch Morris submerged pumps working under a lift of 8 feet. Water was not procured in time for the 1901 crop.

The well at the plant of the Hill-Brown Rice Land and Irrigation Company (C. A. Brown, manager) is an 8-inch, 485 feet deep, the water rising to within 10 feet of the surface. The machinery consists of a Morris direct-connected engine 8 by 8 inches and two 8-inch Morris pumps, the steam being supplied by two 30-horsepower Erie City boilers. The season of 1901 was so dry that no rice was planted. Additions have been made to the plant of this company, and in 1902 the crop was expanded to 1,000 acres.

HARRIS COUNTY.

Harris County systems.—Nearly 90 wells in Harris County are furnishing water for rice irrigation, over half of these being located in the vicinity of Clodine. The following is a list of the plants in this county: Sheldon canal, 2,000 acres; Harris Rice Company, 600 acres; F. B. West, 150 acres; J. E. Ross, 80 acres; A. W. Wilkerson, 250 acres; W. H. Myers, 75 acres; Conrad Bering, 125 acres; C. L. & C. H. Bering, 200 acres; Baldwin H. Rice, 280 acres; Meadow Brook Company, 3,600 acres; S. P. Dickey, 640 acres; F. E. Markeley, 60 acres; J. H. O'Donnell, 650 acres; J. E. Cabaniss, 75 acres; A. Stockdick, 40 acres; E. Couthwaite, 65 acres; plants at Stella, 75 acres; T. J. Roberts, 60 acres; Mrs. Ida W. Baker, 75 acres; total, 9,100 acres.

Sheldon system.—Two and one-half miles from Sheldon, 16 miles east of Houston, the Sheldon Canal Company takes the water for its 2,000 acres of rice this season from the San Jacinto River against a 40-foot lift. The plant consists of one 300-horsepower Corliss engine and one 18-inch Van Wie centrifugal pump. The water is delivered into a flume 226 feet long, which in turn delivers it into the canal, which is 120 feet wide and 4 miles long. The land commanded by the canal lies on both sides of the Southern Pacific Railroad.

O'Donnell system.—Thirteen miles south of Houston, near Erin, on the Santa Fe, J. H. O'Donnell has six wells, 50 feet apart. These are all under 98 feet in depth and have 46 feet of water-bearing sand and gravel; the whole length in sand is screened, and the water rises in the well to within 4 feet of the surface. The power is supplied by four 28-horsepower Fairbanks gasoline engines, which operate the 5-inch Morris pumps. These are placed in pits 15 to 17 feet deep, and are operated in batteries of three each. The soil is black hog wallow, and 650 acres were irrigated during the season of 1902.

Meadow Brook system.—On the Meadow Brook farm, northeast of Clodine, Fort B. Smith has drilled forty-seven wells and has twelve complete plants, ten operated by steam and two by Fairbanks gasoline engines. A complete plant consists of a central steam boiler,

using oil for fuel, and two or three engines, located in either opposite directions from the boiler or in such position as to form a right angle with the central plant. Thus one of these plants consists of a 125-horsepower Erie City boiler operating two 35-horsepower engines, which run the centrifugal pumps. Two wells are connected by piping in each pit, and one pump is then connected to the common junction. These companion wells are about 20 feet apart and are usually 150 deep and 10-inch bore.

Dickey systems.—Sixteen miles west of Houston and 1½ miles north of Daisy, S. P. Dickey has a rice farm where 640 acres were irrigated this season from five wells. These wells are of an average depth of 200 feet, and the power to raise the water is supplied by four 16-horsepower Fairbanks-Morse gasoline engines and one 25-horsepower steam engine. South and southwest of Clodine, in Fort Bend County, are located the well plants of B. A. Evarts, with 125 acres; H. F. Ring, with 165 acres, and F. E. Jones and S. M. Gordon, with 500 acres. The wells are usually 110 and 250 feet deep, connected in the same pit by a T joint.

Seven miles northwest of Houston C. L. and C. H. Bering have a rice farm on the Buffalo Bayou, from which water is taken. The lift is 50 feet. The soil is a black hog wallow. One hundred and fifty acres were irrigated in 1901, commanding from $3 to $3.75 a sack. The plant consists of one 10-inch Hooker duplex steam pump and a 60-horsepower boiler, the capacity being estimated at from 1,500 to 1,800 gallons a minute. In 1902 200 acres were irrigated.

Near the plant just described Conrad Bering had 87 acres in rice in 1901, which he irrigated from three wells, 400, 450, and 500 feet deep, and all being flowing wells the lift is very slight. The wells cost $1,500 each. The 8-inch Knowles duplex pump is on the surface. The yield was 17 sacks to the acre, selling for from $2.75 to $3.50 a sack. In 1902 125 acres were irrigated.

Eighteen miles east of Houston, on Bear Bayou, the Harris County Rice Company (Radford & Co.) had 110 acres of rice in 1901, yielding 1,040 sacks, commanding $3.40 a sack. Their engine is a 125-horsepower Watertown high-speed engine, and their pump a 15-inch Lawrence. The lift is 42½ feet, and the estimated capacity 7,000 gallons a minute. The main canal is 40 feet wide and 1.6 miles long. During the season of 1902 600 acres were irrigated.

Systems near Katy.—In the vicinity of Katy Messrs. J. E. Cabaniss, A. Stockdick, W. J. Nelson, William Eule, and T. G. Roberts have well plants ranging in capacity from 40 to 90 acres for this year. The wells are from 93 to 130 feet total depth and have screens from 12 to 20 feet long. Cabaniss and Eule use Foos gasoline engines of 22 and 14 horsepower, respectively; Stockdick uses a 22-horsepower Fairbanks-Morse, while Nelson and Roberts use steam engines. The Morris pumps are used by Cabaniss, Eule, and Roberts, while Eule

has a Van Wie and Stockdick a Ganed. The acreage is as follows: Cabaniss, 75; Stockdick, 40; Nelson, 90; Eule, 50; Roberts, 60.

Three miles from Genoa, on the Galveston, Houston and Henderson Railroad, A. W. Wilkerson has an irrigation plant consisting of two stations about a half mile apart. At one station there is a 22-horsepower portable engine and an 8-inch Morris pump; and at the other station a 7-horsepower Foos gasoline engine running a 6-inch Morris pump. The water is obtained from 8¼ inch artesian wells 560 feet deep. The soil is a rich black prairie soil. Two hundred and fifty acres were irrigated in 1902.

GALVESTON COUNTY.

Six miles east of Alvin, in Galveston County, near the junction of the Chigre Bayou with Clear Creek, Berry W. Camp, of Houston, has in operation a rice farm of 1,000 acres, which yielded 86 bushels to the acre in 1901. A 150-horsepower Corliss engine operates a 15-inch Van Wie centrifugal pump, which delivers 8,000 gallons a minute (18 second-feet) against a lift of 40 feet. The water is pumped out of an elliptical basin 40 feet across and 17 feet deep, which was excavated in the banks of the bayou and walled in with sheet piling and floored with heavy timber, and is discharged into a flume 2 feet by 6 feet 2,000 feet long and delivered to the main canal, which is 25 feet wide and 2 miles long. Both the Japan and the Honduras rice were sowed, 500 acres of each, the seed being imported for the purpose; 1¾ bushels were sowed to the acre. The soil is black, from 3 to 4 feet deep with a clay subsoil. The best machinery for handling the rice has been introduced. The thresher is the latest improved. It threshes, feeds itself, stacks the straw, sacks the grain (two sacks at a time), and has a capacity of 2,000 bushels every eight hours. In 1902 800 acres were planted.

One and one-half miles south of Algoa Mr. R. B. Halley sunk seven wells from 42 to 45 feet deep early in 1901, arranging them in a battery formation, four on one side and three on the other. Two 4-inch wells connect with a 6-inch pipe, and this 6-inch pipe and a 4-inch pipe join and unite with an 8-inch pipe, while another 4-inch pipe unites with the 8-inch pipe. On the other side two 4-inch wells join with a 6-inch pipe, and this 6-inch pipe and a 4-inch pipe unite with an 8-inch pipe, which is bushed into a 10-inch pipe. The two 10-inch pipes form a T to the pumps. The operating machinery consists of a 22-horsepower Foos portable gasoline engine and an 8-inch Morris vertical suction pump. The pumps are placed 8 feet below the surface. The water rises to within 4 feet of the surface of the ground. After the pumps are started the water level is lowered 10 feet, giving a lift of from 18 to 22 feet. The soil is black prairie soil. The water supply for 1901 failed, and only 250 sacks of "Providence" rice were raised.

BRAZOS VALLEY SECTION.

WASHINGTON COUNTY.

East of the Colorado Valley and from the country along the Santa Fe Railroad to Trinity River there are a number of plants, but they can not be classed in any system geographically distinct. They are in the counties of Washington, Austin, Waller, Fort Bend, Harris, Brazoria, and Galveston. The highest plants in this group are in Washington County and take their water from Brazos River. They are owned by W. E. Buchanan, Heber Stone, and J. P. Buchanan, all residents of Brenham. In 1902 775 acres were irrigated.

The plant of W. E. Buchanan is about 18 miles from Brenham. It consists of a 35-horsepower Atlas engine and an 8-inch Morris pump, having an estimated capacity of 3,500 gallons a minute (nearly 8 second-feet) under the lift of 40 feet. The soil is that of the rich Brazos bottom lands, and 200 acres were planted in 1902.

The plant of Heber Stone is in Waller County, about 18 miles from Brenham. It consists of a 125-horsepower Beaumier Brothers' engine and a 15-inch Van Wie pump. The lift is 40 feet, and the estimated capacity 7,000 gallons a minute (15.6 second-feet). The machinery did not arrive in time for the crop of 1901, but it is the intention to irrigate 200 acres in 1902.

J. P. Buchanan's rice farm is in the neighborhood of the former, but is in Washington County. A 125-horsepower Beaumier Brothers' engine runs the 15-inch Morris pump against a lift of 40 feet, and it is estimated that the capacity is 7,000 gallons a minute. The soil is the famous Brazos bottom land. Forty acres were irrigated in 1901, yielding 50 bushels to the acre, and 625 acres were irrigated in 1902.

The floods in the Brazos in the early part of August, 1902, destroyed most of the rice in Washington County.

AUSTIN COUNTY.

In Austin County there are a few well plants. That of Hackborth & Koy is on Mill Creek, from which it takes its water, 6 miles northeast of Sealy. It consists of an 8-inch Morris pump and a 40-horsepower Erie City engine, working against a lift of 31 feet. The soil is described as a red buckshot with an admixture of black sand. Two hundred acres were irrigated during 1902.

SAN BERNARD CREEK.

Stone system.—On East San Bernard Creek James and Stephen Stone have installed an irrigation system 1½ miles from Beard, with which 390 acres were irrigated in 1900, producing, after the Galveston storm, 6 sacks to the acre, commanding $3 a sack, and 300 acres in 1901, yielding 3,000 sacks, which sold for $3 a sack. The plant con-

sists of one 150-horsepower Westinghouse automatic compound engine, operating a No. 13 Ivens pump having 15-inch suction and 13-inch discharge pipes. The estimated capacity is 7,000 gallons a minute (16 second-feet) under a lift of 27 feet. The flume is 5 feet by 2 feet by 520 feet long, and delivers the water into a canal 2 miles long and 100 feet wide. The laterals are three-fourths mile long and 15 feet wide. The soil is light and sandy, from 1 to 1½ feet deep. Wood is used for fuel, requiring 3 cords a day for the 390 acres irrigated in 1900. The experience here in 1900 confirms the estimate of irrigators in the Beaumont section and in western Louisiana—that it requires fully 9 gallons a minute for each acre irrigated, or 1 second-foot for each 50 acres. In 1902 300 acres were irrigated.

Jahn system.—Just north of Beard G. A. Jahn and associates have opened up a rice farm with the intention of deriving the necessary water from San Bernard Creek by impounding in a reservoir of 100,000 gallons' capacity.

A crib-work dam, 350 feet long, backs the water up 1 mile and deflects it into a canal and pit. The water is then pumped, under a lift of 25 feet, into a reservoir covering 180 acres. The water is pumped out of the reservoir into the supply canals by two 18-inch Van Wie pumps. The power is supplied by a 300-horsepower Corliss engine. This company irrigated 700 acres in 1902. Ten miles southeast of Sealy, and 4 miles north of Chesterville, Dr. Magruder has constructed a dam across the Little Bernard, forming an impounding reservoir from which, with a 28-horsepower engine, he pumped water into 75 acres of rice during the season of 1902. Adjoining the San Bernardo Company, Stephen Stone has dammed a small tributary of the San Bernard, forming an impounding reservoir from which, with a 150-horsepower Westinghouse automatic compound engine and one 13-inch Ivens centrifugal pump, he raises the water into his flumes. In 1902 300 acres were thus irrigated.

FORT BEND COUNTY.

The Fort Bend Irrigation Canal Company has two pumping plants. The second plant pumps from Smithers Lake, which during average seasons has an abundance of water for ordinary purposes. The lake has a drainage area of 14 square miles, and the outlets are dammed to prevent waste. Notwithstanding this, it was evident early in the season of 1901 that the long-continued drought in the coast country, which extended practically from September 8, 1900, to September, 1901, had completely exhausted the resources of the lake. At the second lift the plant is composed of one 50-horsepower Chandler & Taylor engine and one 13-inch Ivens pump, the capacity of which, with the lift of 18 feet, is estimated to be 10,000 minute-gallons. The soil is black prairie land with a good subsoil, 400 acres of which were irrigated during the current season. The plant at the river consists

of an engine of 250-horsepower, operating the pump against a lift of 45 feet. This plant pumps the water into Dry Bayou, and this in turn to Lake Bayou. A dam has been constructed across Rabb Bayou to hold the water from passing out. The acreage in 1902 was 750.

The pumping plant of the Brazos Canal Company is located on Jones Creek, 5 miles north of Richmond, Tex., and 30 miles west of Houston. The water is taken from the creek, which possesses the characteristics of a bayou and acts as a storage reservoir 17 miles long. The lands to be irrigated lie to the west of Houston and fall generally to the eastward from the pumping plant. An extra pumping plant is located on the Brazos River just below the upper junction of Jones Creek with the Brazos, and at low stages the river pumps will have to lift the water 32 feet into the reservoir. A tunnel is excavated from the bayou reservoir to the river, and when the level of the river water rises 32 feet it flows into the reservoir without pumping or it can be shut off if desired. At the second pumping plant the water will be lifted 52 feet into a canal, giving 4 feet of water in the canal, which, with the configuration of the country, can cover the lands to the east by gravity. During 1902 it is intended to irrigate 2,000 acres only.

The Brazoria Rice and Irrigation Company takes its water from the Brazos above a crossing of the Santa Fe with the Brazos. The plant consists of a 900-horsepower Greenwald engine, operating a Worthington high-lift 36-inch pump against a head of 47 feet, and has an estimated capacity of 35,000 minute-gallons. The 100-foot canal from the river conveys the water into a lake of 27 acres about 1½ miles from the river. The water is pumped out of the lake into the second canal by a 450-horsepower Greenwald engine and a 36-inch Worthington pump against a lift of 17 feet. The canals extend at present to the eastward, crossing the tracks of the Columbia Tap Railroad near Riceton. It is contemplated to construct another canal crossing the Santa Fe Railroad and irrigating land south of Arcola Junction. Only 4,800 acres were irrigated by this company in 1902.

BRAZORIA COUNTY.

In Brazoria County the following persons have plants: J. A. Bent, William Masterson, Howard F. Smith, Rod Oliver, H. and G. Munson, F. C. Baker, Judge Walker, A. H. Bartel, and John Chase. Two miles south of Arcola Junction, J. A. Bent has a small plant of about 35 acres, where a small donkey engine and a 4-inch Morris pump raise the required water from a well. The rice farm of William T. Masterson is 4 miles southwest of Sandy Point, and derives its water from Oyster Creek. A 25-horsepower Erie City engine operates an 8-inch Morris pump against a lift of 17 feet and irrigates 30 acres of rice, yielding 250 sacks. H. F. Smith's farm of 175 acres is 1½ miles north of Sandy Point, and derives its water from Jackson Lake.

The plant of Rod Oliver is 10 miles southwest of Angleton. A 25-horsepower engine operates a special pump designed by Mr. Baker, of Angleton, against a lift of 10 feet. It discharges through a vertical penstock 3 feet by 3 feet. Seventy-five acres were irrigated in 1901. The plant of H. and G. Munson is 3 miles west of Angleton, on Oyster Creek, and consists of an 80-horsepower Erie City engine, operating a 15-inch Morris pump, against a lift of 10 feet. This plant was late in being completed, but notwithstanding this 250 acres were irrigated in 1901. Only 100 acres were harvested, however, the yield being 900 sacks, which sold for $2.50 a sack. In 1902 700 acres were irrigated.

The rice farm of Walker & Cain, near Angleton, has three pumping plants. The first is located on Bastrop Bayou and consists of one 150-horsepower engine, operating two 15-inch centrifugal pumps against a lift of 10 feet and having an estimated capacity of 25,000 minute-gallons. The second plant is located on Oyster Creek and constitutes an emergency plant in times of low water in Bastrop Bayou. One 125-horsepower engine pumps the water from Oyster Creek into the canal that leads to Bastrop Bayou. A dam has been constructed across Bastrop Bayou to keep back the salt water, but it also acts as a storage reservoir for the fresh water. Plant No. 3 constitutes the second lift for the main supply canal. It is 2 miles from plant No. 1, and a 75-horsepower engine operates the pumps against a lift of 6 feet and has an estimated capacity of 15,000 minute-gallons. In 1902 1,400 acres were sown.

John Chase also obtains water for his 60 acres of rice from the Bastrop Bayou, 6 miles southwest of Angleton. He harvested only 75 acres in 1901. The pump used is of a special make, manufactured by Mr. Baker, of Angleton. It is run by a 25-horsepower Erie engine and operates under a lift of 8 feet. The crop was badly injured by salt water, the yield being 2 sacks to the acre.

J. G. Smith & Bro. own and operate two rice farms, one 6 miles north and the other 9 miles west of Columbia. The first derives its water from a lake covering 2,000 acres, but the lake failed and the result was no crop. The plant is composed of two Atlas engines of 40 and 25 horsepower and two Morris pumps, one 15-inch and the other 12-inch. The lift is 12 feet and the estimated capacity 6,200 gallons a minute. The plant was first operated in 1900, when 85 acres of rice were raised; but in 1902 the acreage was expanded to 550 acres. The second plant (9 miles west of Columbia) is to derive its water from an 8-inch well 270 feet deep, but it was not completed in time for the 1901 crop. One 40-horsepower Nagle engine runs an 8-inch Morris pump, working under a lift of 10 feet. The soil is a black, waxy prairie soil. This firm also operates a well plant of 60 acres near Guy, in the Fort Bend country.

The plant of A. H. Bartel is 6 miles from Angleton, on the Bastrop

Bayou, and consists of a 25-horsepower engine and a 12-inch Lawrence pump, operating against a lift of 8½ feet. He irrigated 75 acres in 1901, the yield being 135 sacks. In 1902 100 acres were irrigated.

COLORADO VALLEY SECTION.

The principal rice irrigation systems of the Colorado Valley are in Colorado, Wharton, and Matagorda counties. The larger systems are indicated on the map forming fig. 24.

COLORADO COUNTY.

EAGLE LAKE.

Dunovant system.—In 1899 Capt. William Dunovant irrigated 250 acres of rice near the town of Eagle Lake. This was the first rice farm irrigated along Colorado River, and proved so successful that in 1900, 30,000 acres were irrigated in the Colorado Valley, and in 1901 56,000 acres. Water for the Dunovant plant is pumped from Eagle Lake, a beautiful, clear, fresh-water lake near the town of the same name, covering an area of about 2,500 acres and having an average depth of 8 feet. This was the first time the waters of the lake were utilized for irrigation purposes. Captain Dunovant's plant originally consisted of a 12-inch Van Wie double-suction pump, throwing 4,000 gallons a minute. The lift was 27 feet. The three boilers were old-style tubular, which were moved from a sugar mill that had been destroyed by fire. Two had two 14-inch and two 10-inch flues, and the third had two 16-inch and two 10-inch flues. The engine was a 200 horsepower. The flume, which was made of piping, had a length of about 350 feet. With this equipment 250 acres were irrigated in 1899. The plant was added to considerably in 1900. A new 21-inch Ivens pump, having a capacity of 15,000 gallons, and a 150-horsepower automatic engine were installed, and with the other operating machinery 3,000 acres were irrigated. In 1902, 3,600 acres were irrigated.

As Eagle Lake will not supply this plant and that of the Eagle Lake Rice Company, Captain Dunovant and the rice company have each erected pumping plants on Colorado River to pump water from the river to the lake.

The plant has been added to from time to time till it now consists of three pumping stations, two on the lake and one on the river. That on the river consists of a 300-horsepower engine, operating three centrifugal pumps—one 18-inch Morris, one 15-inch Morris, and one 18-inch Ivens—all working under an ordinary lift of 14 feet. The lift would have been much more than this, but the canal to convey the water from the river to the lake was so deepened that the low lift of 14 feet was secured. The old plant on the lake consists of three engines—two of 150 horsepower each and one of 60 horsepower. These operate, against a lift of 22 feet, three centrifugal pumps—one 12-inch Van Wie, one 20-inch Morris, and one 21-inch Ivens. This plant

delivers the water into a flume that connects with the main canal system that crosses the tracks of the Cane Belt Railroad by means of an inverted siphon. The third plant is situated on the lake between the towns of Lakeside and Eagle Lake and is operated by an electric motor that derives its power from the engines at the gin in Lakeside. The pump is a 12-inch Morris and works under a lift of 27 feet. The water is delivered into a flume which connects with a main canal that

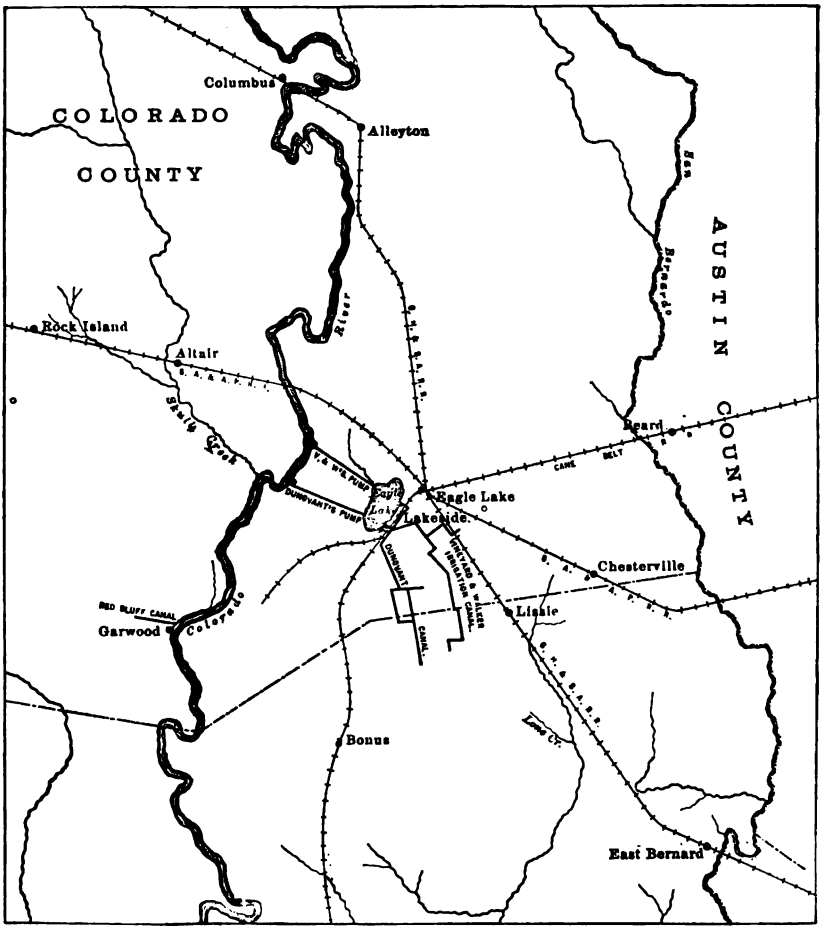

FIG. 24.—Map showing irrigation canals at Eagle Lake.

also crosses the Cane Belt tracks and there parallels the tracks crossing the canal of the Eagle Lake Rice Company's plant and connects with the canal from the original pumping stations. At these stations 80 barrels of Beaumont oil are used for fuel every twenty-four hours. In 1902 3,600 acres were irrigated.

The Eagle Lake Rice Company system (*also known as Vineyard and Walker Canal*).—This company has erected a pumping plant

about one-fourth of a mile north of Captain Dunovant's, on the eastern edge of Eagle Lake, and another on Colorado River, 3 miles from the first plant. The plant on the lake consists of three 125-horsepower boilers and one 250-horsepower engine, operating a 24-inch Ivens pump having a capacity of 20,000 gallons a minute, and one 350-horsepower engine, operating a 30-inch Ivens pump having a capacity of 25,000 gallons a minute. Either of the pumps can be operated from the boilers, but both can not be operated at the same time. This plant is equipped with oil burners and storage tanks and a pipe line from the Cane Belt Railroad. The river plant consists of one 300-horsepower engine and two 150-horsepower boilers (another of the same size is being added), operating a 30-inch Ivens pump of 25,000 gallons capacity, against a maximum lift of 28 feet. The water is canalled to a branch, which takes it into the lake, and from there, in time of low water, is conveyed by means of a canal to the plant across the lake. The river plant has a 3-inch oil-pipe line 7,000 feet long leading from the Aransas Pass Railroad to the plant, also storage tanks, and is fully equipped for burning oil, which has proved a very satisfactory fuel in every way. It is cheaper in first cost, can be applied at less than half the expense for firemen, and is more effective than coal or wood.

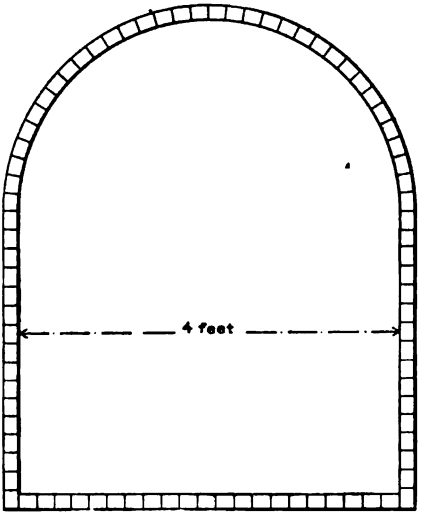

FIG. 25.—Cross section of Eagle Lake Rice Company's siphon under Cane Belt Railroad.

The canal is 60 feet wide at its head, or where the flume enters it, but after the rice farm is reached the width is increased to 100 feet. The total length of the canal is 16,840 feet. The distance from the mouth of the canal to the first gate is 4,300 feet. There are two large laterals leading from the canal, one 4,000 feet long, the other 3,000 feet long. A few hundred feet from its head the canal crosses the Cane Belt Railroad, and this crossing led to a dispute between the canal company and the railroad company. The canal was too high to go under the railroad as graded, and the company would not elevate the track so that the canal could go under. It was finally decided to carry the water under the track by a siphon. This siphon, except under the track proper, is made of brick, the cross sections and dimensions being shown in fig. 25. Owing to the jar caused by passing trains it was considered wise not to extend the brick conduit under the track. Consequently the brickwork stops on both sides, just

before the track is reached, and the water is carried through by means of pipes. The falling and rising curves in the siphon are easy, so as to eliminate as much friction as possible.

The company irrigated 3,000 acres in 1900. In 1901, 3,200 acres were planted, but the supply of water in Eagle Lake failed to such an extent that only a few acres were harvested. It is the intention to sow from 3,000 to 3,500 acres in 1902. The soil on the farm is black and sandy. The contour of the land proves to be of great advantage, for after a certain distance the ground falls, making a second lift plant unnecessary.

COLORADO RIVER.

Sigler system and Harbart-Stafford Rice Company systems.—West of Colorado River, near the stations of Altair and Rock Island, on the San Antonio and Aransas Pass Railroad, several small rice irrigation plants have been introduced. On the west bank of the river a few hundred feet below the railroad bridge, in plain view of passing trains, are the pumping plants of Dr. H. C. Sigler and the Harbart-Stafford Rice Company. The rice farm of the former, which is nearest the railroad bridge, lies along both sides of the railroad track. The plant consists of an 8-inch Wells pump operated by a 35-horsepower Atlas engine. Under a lift of 34 feet the capacity of the plant is estimated at 2,500 gallons a minute (42 second-feet). The plant cost $4,500, and from it 200 acres of rice were irrigated in 1900 (producing 2,500 sacks) and 200 acres in 1902.

The plant of the Harbart-Stafford Rice Company is just below that of Dr. Sigler and west of Colorado River. It consists of a 150-horsepower Atlas engine operating an 18-inch Van Wie suction pump having an estimated capacity of 16,000 gallons a minute (35 second-feet) under a lift of 33 feet from the river level to the flume. The flume is 200 feet long, 5 feet wide, and 2 feet deep, and discharges into the main canal, which is 1½ miles long and 40 feet wide, with 2 miles of laterals 20 feet wide. The plant cost $8,000, and the company planted 350 acres of rice in 1902.

Westmoreland system.—Four miles from the Aransas Pass Railroad bridge J. W. Westmoreland has a rice farm of 225 acres. The water is taken from Colorado River by an 8-inch Morris vertical suction pump. The engine is a 50-horsepower Erie City, and the water is raised to a height of 42 feet.

Four miles east of Rock Island and 1 mile below the crossing of the San Antonio and Aransas Pass Railroad with Skull Creek the Brandon Brothers have a rice farm that derives the necessary water from Skull Creek. The plant consists of a 40-horsepower Erie City engine and an 8-inch Van Wie pump that operates against a lift of 32 feet, and during the season of 1902 irrigated 85 acres of rice.

The total rice acreage in Colorado County west of the river is as follows: From well plants, 840 acres; Brandon Brothers, 85 acres;

J. W. Westmoreland, 220 acres; H. C. Sigler, 150 acres; Harbart-Stafford, 350 acres; Red Bluff Company, 1,200 acres; total, 2,845 acres.

WELL PLANTS.

On the west side of the Colorado River, in the country lying between Rock Island and Garwood, a number of small rice farms that derive their water from wells have been opened up. The wells are somewhat similar in construction and always consist of a pit, either circular or rectangular in cross section, excavated to a depth of 18 to 22 feet, with a bored well in the bottom. This well must always extend through sufficient water-bearing sand and gravel to give flow enough for the farm. A screen must be let into the sand strata, which will keep the sand as far as possible out of the pipes and will admit sufficient water. These screens are of various forms and lengths, and upon the screens often hangs the success of the whole enterprise. The first step in a scheme of this kind is to get a well. Nothing further should be done till the well is an assured fact. The screen can be of side or end suction. In the former case the pipe is perforated with holes one-half to three-fourths inch in diameter, 2 to 3 inches apart. Around the pipe is then wrapped fine wire, almost touching, and over this a copper gauze is stretched, the mesh varying with the kind of sand, and often experience is the only sure test. The end-suction screen will be described later. The wells of Baker Brothers and W. C. Jones will serve to illustrate those west of the river in Colorado County. The Baker well has a screen 27 feet long at the bottom of a 67-foot well, while the Jones well encountered water at a depth of 34 feet, and from this depth was placed a 30-inch screen 29 feet through coarse gravel. The suction pipe is attached to the screen pipe, and generally a centrifugal pump is placed in the bottom of the pit, and the vertical shaft extends several feet above the surface of the ground. A pulley is mounted on this shaft and is operated from the engines by belts. The engines are generally, for a single well, small steam engines of 15 to 40 horsepower, or gasoline engines of 12 to 28 horsepower. A good well outfit ought to be put in for about $1,600. The well plants west of the river in Colorado County are as follows: Frank Marshall, 50 acres; Berry Brothers, 90 acres; E. D. Bone, 135 acres; W. C. Jones, 200 acres; John Duncan, 100 acres; Baker Brothers, 100 acres; Berry, Cox, Johnson, 85 acres; Will Carr, 80 acres; total, 840 acres.

Just north of Garwood the plant of the Red Bluff Rice Company takes its water from the Colorado River. The plant consists of two 150-horsepower Erie City boilers and one 300-horsepower Corliss engine. Water is pumped from the Colorado River, and 1,200 acres of rice were irrigated in 1902. The lift is 42 feet and the pump is an 18-inch Morris centrifugal and has an estimated capacity of 15,000

minute-gallons. The water is delivered into a flume 600 feet long and then into the main canal, which is 100 feet center to center of embankments and 1½ miles long. The laterals are about 30 feet center to center of embankments and about 1 mile long.

Marshall system.—Within the neighborhood of Rock Island, on the Aransas Pass Railroad, there are a number of projected rice farms and a few that were ready at the opening of the season of 1901. Two miles south of Rock Island, Frank Marshall has a well 78 feet deep, from which water is forced by a 6-inch Morris pump operated by a 35-horsepower Erie City engine. The plant cost $1,500, and although it was late in the season before it was ready for work, 100 acres were irrigated in 1901.

Small system.—Nine miles south of Rock Island, A. W. Small owns a plant consisting of a 6-inch Morris pump and a 35-horsepower Erie City engine. The lift is 40 feet, and the plant is estimated to possess a capacity of 1,050 gallons a minute. Ninety acres were irrigated in 1901. The cost of the plant was about $1,600.

In that section lying east of the Cane Belt Railroad and between Sealy, Hungerford, and East Bernard there are twenty well plants, averaging two wells to the plant, the acreage varying from 75 to 550. These plants, lying mostly in that section bounded by Eagle Lake, East Bernard, and Chesterville, have a common bond, in that they obtain their water from the water-bearing sand lying under the upper, blacker soil. A few typical plants will be described.

Vick system.—About 2 miles east of Eagle Lake, George Vick has installed a plant to irrigate from wells. In 1900 he sunk a well 12 feet in diameter and 34 feet deep, and with an Ivens submerged pump discharging through a 5-inch force main he irrigated 125 acres of rice. The pump was operated by an Avery traction engine, which is also used for traction purposes. The water was discharged into a small flume 12 inches by 12 inches, which in turn discharged into a ditch 25 feet wide and 1 mile long. In addition to the 125 acres irrigated from the pumps, 25 acres were irrigated by damming a small stream and forming a storage reservoir. In 1900 Mr. Vick sowed 1½ bushels to the acre, but increased this to 1¾ and 2 bushels an acre in 1901. The crop of 1900 was damaged by the Galveston storm, but notwithstanding this he realized 19 bushels to the acre, which sold for from $1.50 to $4.25 a sack. The total cost of the plant used in 1900 was $2,250. This plant is now owned and run by Hudson & Ayres. A new 45-horsepower Erie City engine has replaced the traction engine. Beaumont oil is used as fuel, and it requires about 3 barrels for a a twenty-four-hour run. In 1902 165 acres were irrigated.

Adams system.—The feasibility of using windmills for rice irrigation was thoroughly tested at the farm of Adam Adams, 4½ miles east of Eagle Lake. He installed nine Gamble long-stroke wind-

mills, each having a 3-inch by 14-inch cylinder and a 10-foot wheel, operating pumps having 2-inch suction and discharge pipes against a lift of 25 feet from the seven wells that furnish the water. The plant cost $825. The water is discharged into a reservoir 4 feet deep covering 15 acres and having a capacity of 174,240 cubic feet. It is estimated that the windmills have a capacity of 70 gallons a minute.

The windmills proved insufficient, and they have been abandoned. A Fairbanks-Morse 22-horsepower gasoline engine, operating a 6-inch Morris centrifugal pump, is now used to raise the water to the flume. Eighty acres were irrigated in 1902.

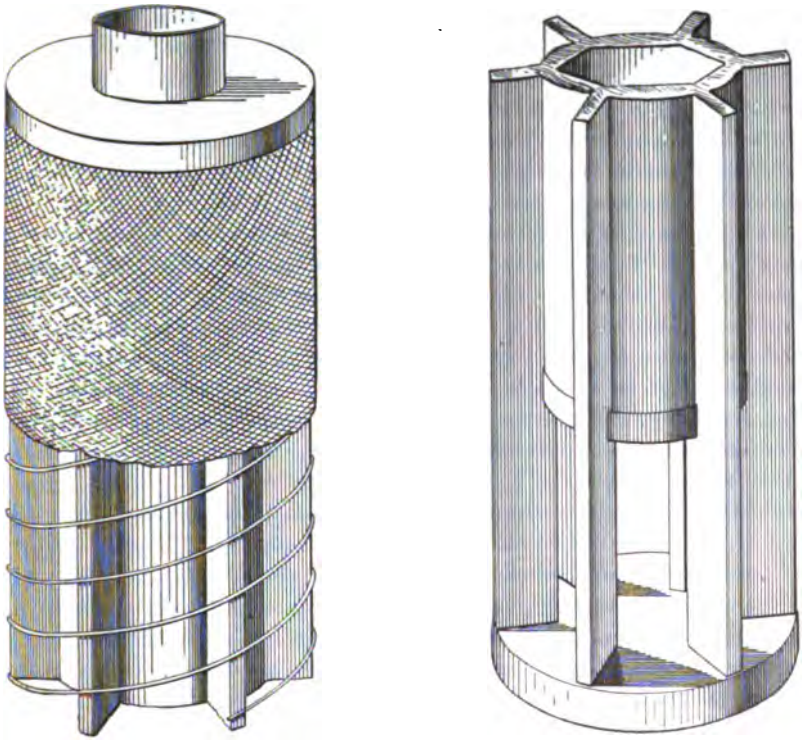

FIG. 26.—Sand screen for water wells.

A typical surface well for the Chesterville plants would be 41 to 44 feet deep, 19 feet to water-bearing sand, and then 20 to 25 feet of sand, followed by clay. A very successful screen with bottom suction 8 feet long is used in this neighborhood. It consists of a wooden pipe about 8 inches in diameter, from which 6 to 8 radial vanes project about 6 inches. A heavy wire is wrapped spirally around the vanes, making another cylinder, varying in diameter from 24 to 36 inches. Around the wrapped cylinder on top of the wire is attached a wire gauze with a mesh of 24 to the inch, which holds back the sand, permitting the water to enter. The vanes extend below the bottom

of the pipe and are attached to a bottom cap, thus leaving an open space for the water to enter the bottom of the central wooden cylinder. The suction pipe of the pump is attached to the wooden cylinder near the top of the screen. A good well and a good screen are the sine qua non for a successful well plant. All failures can be traced to their absence. This is the reason that active plants of 1901 are idle in 1902. They constitute the foundation stone of success in the prairie rice farm. Without them the biggest pumps in the State could not raise water. Many plants in Texas in the last two years have been started at the wrong end. Elaborate canals, excellent machinery, fine, black, hog-wallow land are futile without sufficient water of the right kind. At plant No. 2 of John Linderholm, at Chesterville, 1,350 acres of rice were irrigated in 1901, although a late start was made. The machinery consists of a 28-horsepower gasoline engine, operating a 6-inch Van Wie pump. The plant cost $2,150; expenses, $500; and the crop paid for the plant, expenses, and the land, estimated at $12.50 per acre. This season Watt's refined Beaumont oil is used as a fuel in the gasoline engines.

Foster system.—In the neighborhood of Chesterville, 7 miles east of Eagle Lake, H. L. Foster has installed a plant to derive its water from a well. One 20-horsepower Erie engine runs a No. 4 Morris pump having 5-inch suction and 4-inch discharge, which has an estimated maximum capacity of 600 gallons a minute (1.33 second-feet) against a head of 21 feet. The canals are three-eighths mile long and 6 feet wide. Unfortunately the water supply proved a failure, and additional wells will have to be dug to obtain sufficient water for the rice land.

Linderholm system.—One-fourth mile from Chesterville, John Linderholm has three of the most effective well plants in Texas. Three No. 6 Van Wie pumps, having 8-inch suction and 6-inch discharge, and one No. 3 Van Wie pump, having 5-inch suction and 3-inch discharge, are operated by four Fairbanks & Morse engines of 34, 28, 34, and 12 horsepower, respectively, against a lift of 20 feet, estimated to have a capacity of 8,000 gallons a minute (18 second-feet). The wells are on the highest points of the land, and no flumes are necessary. Two reservoirs have been constructed, but so far they have not been utilized. The soil is a sandy loam, and the 125 acres irrigated in 1900, notwithstanding the Galveston storm, produced 8 sacks of rice to the acre, commanding $3.50 per barrel of 162 pounds. Four hundred acres were irrigated in 1901, the yield being 9½ sacks to the acre, commanding from $3 to $3.10 a barrel. Land is rented on the usual one-half plan, i. e., one-fifth of the crop for land, one-fifth for water, and one-tenth for seed. Gasoline is used as fuel. The engines are run twelve hours a day, and require 2,592 gallons of gasoline (74 per cent proof) daily, or 2 gallons per hour per horsepower. The three plants watered 550 acres in 1902.

Gray system.—Near Lissie, George Gray has installed a 28-horse-

power Fairbanks & Morse gasoline engine, which operates a Van Wie pump having a 6-inch discharge pipe and an estimated capacity of 22,000 gallons a minute (5 second-feet). The plant cost $4,500. The water is supplied by two wells, one an 8-inch well 103 feet deep, with 91 feet of water, the other a 10-inch well 140 feet deep, with 115 feet of water. The main canal is three-fourths mile long and 8 feet wide. The soil is black and sandy, with a clay subsoil. One and one-fourth bushels of rice are sowed to the acre. For the land rented one-fifth of the crop is charged for land rent, one-fifth for water, and one-tenth for seed—i. e., for land, water, and seed, one-half of the crop is charged. In all 120 acres were irrigated in 1901, but the cold weather ruined 50 acres. The 70 acres saved yielded 740 sacks. A second plant has been added, and 400 acres were planted in 1902.

Malmquist system.—C. T. Malmquist irrigated 38 acres from one well by an 8-horsepower Fairbanks & Morse gasoline engine, operating one No. 4 Ivens pump having 5-inch suction and 4-inch discharge pipes, and an estimated capacity of 600 gallons a minute (1.33 second-feet) under a lift of 16 feet. The plant is 1 mile from Chesterville. The yield was 300 sacks, which sold for $3.15 a sack.

McLain system.—Four and one-half miles from Chesterville George McLain irrigates 160 acres from two wells. One Charter 18-horsepower gasoline engine runs a No. 4 Van Wie pump having a 5-inch suction and a 4¼-inch discharge. The plant has an estimated capacity of 1,200 gallons a minute (2.67 second-feet) under a head of 15 feet. Only 5 acres were planted in 1900, and the crop was considerably damaged by the Galveston storm. The soil is black and waxy, and produced 7 sacks to the acre in 1900. The water supply failed in 1901, and Mr. McLain raised no rice.

Townley system.—The plant of J. C. Townley, three-fourths mile from Chesterville, consists of one No. 8 Morris pump having 9-inch suction and 8-inch discharge, operated by a 35-horsepower Erie City engine. The lift is 20 feet and the estimated capacity 1,700 gallons a minute (3.8 second-feet). The soil is black and sandy. Two hundred acres were irrigated in 1901. The plant, exclusive of land, cost $3,000.

Electric system.—Instead of having several distinct power plants, each to carry its own pump and acreage, the Bernard Rice and Irrigation Company (C. B. Sloat, manager) has erected on its plant, 2 miles east of Lissie, a central power plant, consisting of a steam engine and boiler of capacity sufficient to carry two whole pumping plants. The power is conveyed to a 75-kilowatt electric motor, and by this the power is transmitted electrically by wire to smaller motors of 20-horsepower capacity at the three pumping plants on the farm. The experiment will demonstrate clearly the most economical method of operating plants where pumps are located in different parts of the farm.

WHARTON COUNTY.

Hudgins Brothers system.—Seven miles east of Wharton the Hudgins Brothers have opened up a large rice farm and are giving wells a full and fair test. They have in all eleven wells; seven are 44 feet deep and four are 36 feet deep. The pumps are about 13 feet below the surface. There are ten No. 3 and one No. 1 Van Wie rotary pumps. The former cost, exclusive of freight, $85 each, the latter $115. The pumps are operated by gasoline engines, five of 22 horsepower and one of 16 horsepower. Eleven hundred acres of Japan rice were irrigated in 1901, but only 450 in 1902.

The acreage from well systems in the section between Sealy and Hungerford is shown in the following: Hudson & Ayers, 165 acres; W. W. Miller, 200; R. B. Dobbins, 100; J. E. Irvin, 40; Adam Adams, 80; John Linderholm, 550; J. C. Townley, 200; C. T. Malmquist, 60; W. S. Strickland, 100; George McLain, 150; George Gray, 400; Bernard Rice Company, 205; H. Cordz, 300; Paul Jackets, 80; McBride & Lester, 100; W. S. Moore, 100; L. Pietsch, 170; Longworth & Caylor, 300; Hudgins Brothers, 450; J. M. Everett, 140; total, 3,890 acres.

EL CAMPO SYSTEMS.

In the section of Wharton County west of the Colorado River, along the line of the New York, Texas and Mexican Railroad, near the stations of Pierce, El Campo, and Louise, more well plants are in operation than in any other section of Texas. Two systems of wells are used, the shallow and the deep. The shallow wells are all of one general type. A pit, rectangular or circular in cross section, is excavated to the depth to which the water will rise, and in the bottom of the pit one or more wells are bored through or into the water-bearing sand or gravel. In this is placed the screen. The pits vary in depth from 10 to 19 feet, and the wells from 40 to 70 feet. The soil is generally black and sandy, underlain by clay, which lies over the water-bearing sand. The Milner well, a mile west of Pierce, will serve as a type for the deep wells. This well is 180 feet deep, 10-inch bore, and has 60 feet of screen. The log shows 14 feet of black soil, thick stratum of red clay, 6 feet of quicksand, 4 feet of clay, 16 feet of coarse sand and gravel, and three thin layers of clay alternating with thicker strata of sand and gravel. This well and its companion shallow well (both in the same pit) constitute in their combined capacity by far the best well found in the Texas rice belt. One of the best shallow-well plants found in this section is that of Fred Blumquist, 1½ miles east of El Campo, which is described later.

A few typical plants are here described.

Brunes system.—The plant of Chris. Brunes is just east of the Beard plant. It consists of a 5-inch Morris pump operated by a 20-horsepower Advance traction engine. The well is 48 feet deep, the water rising to within 19 feet of the surface. The head is 24 feet

and the capacity estimated at 800 gallons a minute. The engines, pumps, belts, etc., cost $1,500. Fifty acres were irrigated in 1901, yielding 785 sacks, commanding $3.10 a sack.

Nordin system.—P. H. Nordin's plant is 2 miles north of El Campo. The well is 48 feet deep, the water being 20 feet below the surface. He uses a 20-horsepower J. I. Case traction engine and a 6-inch horizontal centrifugal pump. The capacity is estimated to be 700 gallons a minute under a head of 21 feet. The engine and pumps cost $1,350. Fifty acres were irrigated in 1901, yielding 413 sacks.

Just east of this plant is the plant of J. B. Carlson, which irrigated 50 acres of rice in 1900, the yield being 350 sacks. The pit of the well is 8 feet in diameter and 25 feet deep; the bored part of the well is 27 feet, making a total depth of 52 feet. The pump, a 6-inch Van Wie, is in the bottom of the pit, and has a lift of 26 feet. It is operated by a 16-horsepower Fairbanks & Morse gasoline engine. A test made at this plant shows that it requires 46 gallins of gasoline each twenty-four hours, or nearly 3 gallons to the horsepower. In carload lots the gasoline costs 12 cents a gallon, delivered at El Campo.

A second pumping plant run by a traction engine is conducted by Mr. Carlson.

Olesen system.—Five miles north of El Campo is the rice farm of D. Olesen. The well is 52 feet deep, 7 feet in diameter for 25 feet and bored the rest of the way. As at all of these plants, the water is pure, fresh, and as clear as crystal. The plant consists of a 5-inch Morris vertical pump and a 20-horsepower Advance compound traction engine, and cost $1,500. The pumps are 22 feet below the surface of the ground, giving a lift of 27 feet. The estimated capacity is 750 gallons a minute. Thirty acres were watered in 1901, the yield being 150 sacks.

Higbee system.—In 1901 R. E. Higbee irrigated 98 acres of Honduras rice, the yield being 1,500 sacks. The soil is a black hog-wallow. The well is 48 feet deep, the water rising to within 13 feet of the surface. The plant is 1 mile east of El Campo and consists of a 6-inch Van Wie pump and a 25-horsepower J. I. Case engine. The lift is 17 feet, and the capacity estimated at from 1,200 to 1,500 gallons a minute.

Berglund system.—P. E. Berglund uses a 35-horsepower Weber gasoline engine and a 6-inch pump. His well is 34 feet deep, the water level being 12 feet below the surface. The rice is sowed with a seeder attached to the hind gate of a wagon. Thirty-five acres were irrigated in 1901, the yield being 450 sacks.

Blumquist system.—One and one-half miles east of El Campo Fred Blumquist irrigates 35 acres, the yield in 1901 being 741 sacks, 4 bushels to the sack. He sold part for seed rice at $3.25 to $3.50 a sack. His pumps are in a pit 8 feet by 10 feet. The well is bored in the bottom of the pit to a depth of 30 feet, making the total depth of well 40 feet. The pump is a 5-inch Morris horizontal rotary working under a lift of

15 feet, and the engine a 14-horsepower Foos gasoline. The cost of all was $970.

Danielsen system.—The pump, lift, and engine of A. Danielsen are similar in all respects to those of Blumquist. Sixty acres were irrigated in 1902, yielding 700 sacks, which sold for $3 a sack.

Embry system.—The farm of J. R. Embry is 4½ miles east of El Campo. The soil is a black hog-wallow. Ninety acres of rice were irrigated in 1901, yielding 625 sacks. The pit is 4 feet by 16 feet by 6 feet deep. Two 8-inch wells were bored in the pit to a depth of 34 feet, making a total depth of 40 feet. The water rises to the bottom of the pit. An 18-horsepower gasoline engine runs the 6-inch Morris horizontal rotary pump against a lift of 8 feet.

Schult system.—Six miles east of El Campo Oscar Shult has opened up a rice farm on which 100 acres of rice were irrigated in 1901, the yield being 858 sacks. The source of water is a well 39 feet deep. The pit is 8 feet by 9 feet by 9½ feet deep. The bored part (30 feet) is 14 inches clear diameter. The machinery consists of an 18-horsepower gasoline engine and a 6-inch Morris horizontal rotary pump. The soil is a black hog-wallow, and both the Honduras and the Japan rice will be tried. Fifty-five pounds of Japan (1⅓ bushels) and 1½ bushels of Honduras were sowed to the acre.

The well camps around El Campo are all similar, the greatest variation being in the machinery of operation. No attempt is made to give the individual peculiarities of each plant, as a few typical plants cover the essential features. The extent of the well system tributary to El Campo and Pierce is shown by the following list: O. R. Johnson, 153 acres; Oscar Nelson, 60; A. Danielsen, 80; Fred Blumquist, 120; A. P. Olesen, 60; R. E. Higbee, 70; N. Thompson, 200; A. Burglund, 50; T. Rolf, 40; Axel Bard, 60; J. W. Leech, 160; W. H. Waugh, 100; J. R. Embry, 75; Johnson & Jensen, 70; Oscar Schult, 250; James Milner, 750; P. A. E. Nelson, 50; A. P. Borden, 50; N. J. Sunwall, 50; M. Barnhardt, 25; A. P. Borden, 50; W. S. Wood & Co., 300; Chris Brunes, 105; P. H. Nordin, 105; Boehm Brothers, 60; J. B. Carlson, 175; Nelson Brothers, 200; Fritz Bender, 60; A. E. Carlson, 75; Woolsey, 120; A. S. Thompson, 75; O. B. Scroggins, 50; W. S. Louis, 75; E. G. Sterner, 150; L. Cahn, 60; John Bacek, 30; William Neizer, 50; Frank Garetzky, 50; John Wetzel, 50; T. A. Hill, 120; total, 4,200 acres.

Louise systems.—Near Louise station, on the Texas Mexican Railroad, over 1,200 acres of rice were sowed in 1902, but of the seven plants only two had sufficient water. A successful typical well here has hardly been formed. The well of W. G. Davis presented some peculiarities. At 96 feet a granite-like rock was encountered, and the drill cut through a 4-foot layer of this, making the well 100 feet deep in all. The suction pipe was set directly on top of this rock, and no screen was used. The well furnished more than an ample supply of clear, fresh water. The machinery consists of a 22-horsepower Foos gasoline engine and a 6-inch Morris pump. Sixty acres of Japan rice

were irrigated during the season of 1902, but the well had water for double this acreage. The following is a list of the plants near Louise, with the amount of rice sowed: W. G. Davis, 60 acres; G. W. Barnett, 50; Otto Peterson, 40; E. M. Clark, 400; Saddler & Rome, 250; Saddler & Thomason, 200; Saddler & Thomas, 240; total, 1,240 acres. When visited in July the only plants that had water on them were the Davis and the Peterson, and it is very probable that the Louise plants will not average over half a crop this year.

JACKSON COUNTY.

Moritz and Mayfield systems.—Near Ganado, just over the line in Jackson County, M. P. Moritz and D. B. Mayfield have opened up rice farms of about 100 acres each. The former uses a 5-horsepower gasoline engine to pump from a well 56 feet deep with 20 feet of water-bearing sand. It is estimated that in a dry year one good well will irrigate 80 acres of rice. The Mayfield plant adjoins that of Moritz, and derives its water from a well 67 feet deep with 30 feet of water-bearing sand.

The acreage around Ganado in 1902 was as follows: D. B. Mayfield, 50; N. P. Mauritz, 200; A. W. Everitt, 50; L. Ward, 75; Boquette, 60; total, 430 acres.

COLORADO RIVER BELOW WHARTON.

Bay Prairie Irrigation Company system.—Eight miles below Wharton and surrounding Lane City is the rice farm of the Bay Prairie Irrigation Company (often called the Lane Company). The pumping plant is on the banks of Colorado River, from which it takes its water, at a distance of 16,700 feet from the depot at Lane City. There were two pumping plants in 1901, but it is intended to add a third in order to bring more land under ditch. When completed the system will command 15,000 acres. The plant at the river consists of two Van Wie pumps having 54-inch discharge, operated by a Bates-Corliss engine of 1,250 horsepower. The lift is 33 feet, and the capacity is estimated at 70,000 gallons a minute. The engineer, L. E. Beadle, estimates that it will require 8 gallons a minute for each acre, but he has provided for emergencies by installing pumps having a capacity of 10 gallons a minute for each acre. There are two flumes, one at the river and the other across Jarvis Creek. The former is 5 feet by 12 feet by 182 feet long, while the latter, which is 1¼ miles from the river, is 4 feet by 20 feet by 350 feet long. There are 11 miles of main canals 120, 100, and 80 feet wide. At the second lift an Atlas-Corliss engine of 200 horsepower operates a 24-inch Van Wie pump estimated to have a capacity of 30,000 gallons a minute under the lift of 5 feet. The soil is black. The farm lies on each side of the Cane Belt Railroad. The water is carried under the tract by a terra cotta and timber invert. The plant, exclusive of land, cost $125,000. Six thousand five hundred acres were irrigated in 1901. It is intended to increase this in 1902 to 15,000 acres. This company

offers the most liberal terms to renters of any irrigation systems examined. It furnishes land, water, and seed for three-sevenths instead of one-half of the crop, thus giving the renter an advantage of 6 per cent.

Since writing the above the third lift has been added and the plant at the second lift has been transferred to the third lift. The capacity of the river plant is now 120,000 minute-gallons, and the plant at the second lift consists of one 250-horsepower engine, operating a 45-inch

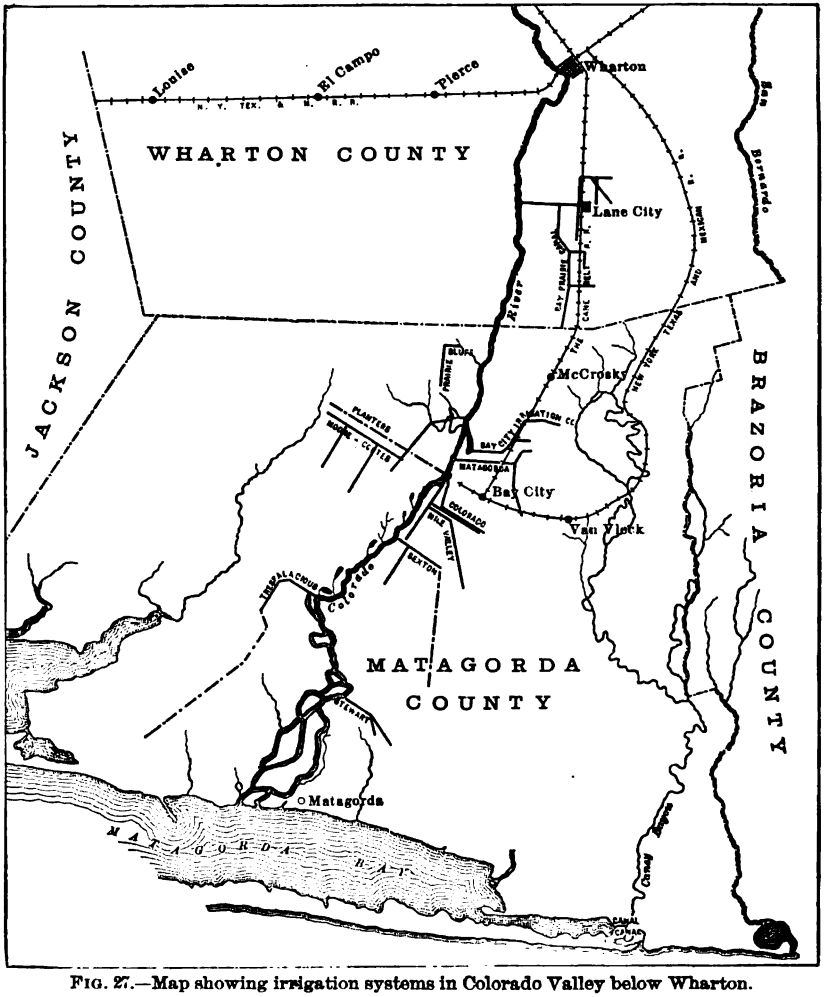

FIG. 27.—Map showing irrigation systems in Colorado Valley below Wharton.

centrifugal pump which has a capacity of 50,000 minute-gallons; at the third lift, a 200-horsepower Atlas-Corliss engine, operating a 24-inch Van Wie pump, which, with the lift of 3½ feet, has a capacity of 20;000 minute-gallons. In 1902 there were under the first lift 9,500 acres, under the second 5,000, and under the third 1,500, making a total of 16,000 acres under canal, and 15,000 acres of these were irrigated during the current season.

A. BUILDING LEVEES FOR RICE-FARM CANALS, WITH ENGINE AND GRADING MACHINE, IN MATAGORDA COUNTY.

B. BREAKING SOD WITH ENGINES, FOR RICE PLANTING, NEAR BAY CITY, MATAGORDA COUNTY, MARCH, 1902.

Capacity of engine, about 50 acres per day and night.

MATAGORDA COUNTY.

Near Bay City, in Matagorda County, eight large companies have opened up extensive rice farms. The Bay City Irrigation Company, the Nile Valley Company, the Colorado Company, the Stewart, the Sexton, and the Matagorda Rice and Irrigation Company have plants on the east side of the river, while the Moore-Cortez, the Planters, the Prairie Bluff, and the Trespalacious are on the west side, as shown by fig. 27. Not only is heavy machinery used in pumping the water, but the heaviest traction engines are used both in making the levees and in plowing the land. One traction engine of 30 horsepower, with its plows, can break up 2 acres per hour. Pl. VIII, *A* and *B*, shows the methods of levee making and steam plowing.

Moore-Cortez Canal Company system.—The Moore-Cortez Canal Company installed for the season of 1901 a large plant about 6 miles from Bay City. They own and control 20,000 acres of land, and have located their pumps on a small lake. The plant consists of one 300-horsepower Vilter-Corliss engine, operating an Ivens centrifugal pump having two 30-inch suction pipes, and an estimated capacity of 56,000 gallons a minute (124 second-feet) under a lift of 12 feet. The main canal is 7 miles long and 100 feet wide. The length of the main laterals is 10 miles and the width 40 feet. The whole plant, exclusive of land, cost $50,000. Five thousand five hundred acres were irrigated in 1901, yielding 10 sacks to the acre, selling for from $2.50 to $4.50 a sack. For the part of the land that is rented the company charges one-fifth of the crop for land rent and one-fifth for water. In 1902 10,000 acres were irrigated.

Bay City Irrigation Company system.—The pumping station of the Bay City Irrigation Company (Victor La Tulle, manager) is 3 miles north of Bay City and takes water from a lake connected with Colorado River. The plant consists of two 24-inch Morris pumps and two 140-horsepower Erie City engines. The capacity is 50,000 gallons a minute (111 second-feet) under a head of 12 feet. The water is delivered into a flume 3 feet by 12 feet 100 feet long. There are 7 miles of main canals, 125 feet from center to center of embankments. The cost of the plant, exclusive of land, was $30,000. The soil is a black hog-wallow with a slight admixture of sand. The plant was operated for the first time in 1901, when 4,000 acres of rice were irrigated, producing 10 sacks to the acre. This plant watered 5,000 acres in 1902.

Matagorda Company system.—Adjoining the lands of the Bay City Company are those of the Matagorda Company. The pumping plant is 2 miles northwest of Bay City, and consists of one 360-horsepower Greenwold engine and one 100-horsepower Nagle engine. There are two Worthington pumps and one Menge pump. The discharge pipes of the Worthington pumps are 20 inches by 40 inches, while the Menge pump discharges through a penstock 6 by 6 feet. The joint capacity of the former is 64,000 gallons a minute and of the latter

22,000 gallons a minute, or a total of 86,000 gallons (191 second-feet), under a lift of 98 feet. It is to be remarked that this is about equal to the lowest flow of Colorado River at Austin. The total cost of the plant, exclusive of land, was about $55,000. The plant was used to irrigate 540 acres of land in 1900, the yield being 12 sacks to the acre, which commanded $3.60 a sack, net. In 1902 the acreage was increased to 9,000 acres.

Colorado Company system.—Near the Matagorda plant is that of the Colorado Canal Company. This plant is located on an intake connecting with a lake, which in turn at certain stages of the river connects with it. The machinery consists of a Murray Brothers 200-horsepower compound condensing engine and a Connersville blower pump, with discharge pipe 32 by 96 inches. The lift varies from 8 to 12 feet, depending upon the stages of the river and lake. It requires 20 barrels of Beaumont oil per day, which costs at Bay City 43 cents per barrel, making a total cost of $8.60 per day for fuel. The capacity of the plant is 50,000 minute-gallons. During the present season 5,300 acres were irrigated.

Nile Valley system.—The Nile Valley plant is on the banks of the Colorado River, less than one-fourth mile from that of the Colorado Company. This plant takes its water directly from the Colorado River one-half mile above the head of the famous raft. Two 80-horsepower duplex engines operate the two 30-inch Morris pumps against the maximum lift of 8 feet. The canal of this company forms a levee and serves to protect Bay City and the lands below. Twenty-two barrels of Beaumont oil are used per day. In 1900 2,500 acres were irrigated from this canal. Pl. IX, *A*, is a view of the pumping plant at the Nile Valley plant.

Stewart system.—At the Stewart canal an 80-horsepower engine operates a 24-inch Morris pump against a maximum lift of 21 feet. In 1902 1,700 acres were irrigated by this canal.

Sexton system.—The Sexton plant uses a simple 80-horsepower Greenwald engine and a Menge pump under a lift varying from 18 to 20 feet. This plant irrigated only 500 acres this season. On the west bank of the Colorado River two new plants have been projected, the Trespalacious and the Planters. The former is below Bay City, while the latter takes its water from below the Moore-Cortes pumping plant, but its canal crosses that of the Moore-Cortes Company and irrigates land above. The Planters Canal Company was late in starting, and only 950 acres were irrigated in 1902. The Prairie Bluff Rice Company has located its canal on Blue Creek above the Moore-Cortes and the Planters canals. It also was late in starting, and during the current season irrigated 350 acres of rice.

Summary of Matagorda plants.—Following is a summary of the Matagorda County plants: Bay City Irrigation Company, 5,000 acres; Matagorda County Rice Company, 9,000; Colorado Company, 5,300;

A. NILE VALLEY PUMPING PLANT.

B. BALING RICE STRAW FOR HAY, NEAR BAY CITY.

Nile Valley Company, 2,500; Stewart Canal Company, 1,700; Sexton Canal Company, 500; Prairie Bluff, 350; Moore-Cortes, 10,000; Planters Canal Company, 950; S. J. Cleveland, 160 acres; total, 35,460 acres.

GUADALUPE RIVER.

DEWITT COUNTY.

The only water-power plant in Texas that irrigates rice is that of Otto Buchel, 3 miles north of Cuero. A masonry dam across the Guadalupe River produces an effective head of 10 feet. This is one of the most substantial dams in Texas, and it cost, with its equipment, $100,000. The power is generated by 54-inch turbines, which operate the pumps to raise water into an adjacent reservoir. An auxiliary steam plant of 400 horsepower is used for supplementing the energy generated by the water plant. This plant furnishes power for three rice farms—Mr. Buchel's, Schleicher & Crouch's, and Rathbone and Wofford's. The farm of Schleicher & Crouch is above that of Buchel and on the east side of the river. The power for operating the pumps is transmitted electrically from the Buchel power plant. The farm of Rathbone & Wofford is on the west side of the river, and also receives its power by electric transmission from the Buchel plant. In all, 750 acres of rice were irrigated at these farms in 1902.

VICTORIA COUNTY.

The plant of the Victoria Rice and Irrigation Company is located 10 miles south of Victoria, and takes its water from the Guadalupe. On the east side, at the first lift on the river, there are two 235-horsepower Brownell engines operating the pumps against a lift of 22 feet. The river plant delivers the water into a flume 1,400 feet long, and this empties into a reservoir 24 by 125 feet by 9 feet deep. The second lift is 41½ feet, and two 525-horsepower Corliss engines operate the pumps. The second flume is 400 feet long and delivers the water into the main canal. There are 5 miles of 100-foot canals, 2 miles of 75-foot laterals, and 2 miles of 60-foot laterals. The highest point of land to be irrigated is 62 feet above the ordinary water level of the river, and there is a fall of 18 inches from the second lift to this highest land. In 1902 2,700 acres were irrigated. Wood is used as fuel at present, but it is the intention to substitute Beaumont oil soon, transporting it down the canal by boat to the plants.

Four miles west of Victoria Harry Rathbone has 60 acres in Japan rice this season. He derives the water from Pridhams Lake, and a 6-horsepower engine operates the 5-inch centrifugal pump under a lift of 8 feet. The soil is sandy river bottom. Twelve miles above Victoria John T. Rusk has a well-plant rice farm, but lateness in obtaining water renders its acreage doubtful for this season.

BROWNSVILLE IRRIGATION SYSTEM.

The center of rice culture in Texas takes its way considerably westward for 1902, on account of the big irrigation system near Brownsville, on the Lower Rio Grande. During 1901 this system was experimental, consisting of the machinery of an unused irrigation plant. The experiment was so successful, however, that the company, the Brownsville Land and Irrigation Company (W. M. Ratcliff, manager), has made plans to extend the system on a large scale, at a cost of $250,000. The plant is 5½ miles below Brownsville. Rice, sugar, and cotton will be raised by irrigation. The plant now consists of one 300-horsepower Chandler & Taylor engine and an Ivens centrifugal pump, having 28-inch suction and 24-inch discharge pipes, and an estimated capacity of 80 second-feet under the lift of 11½ feet. The horsepower of the engine, if actual, ought to treble this discharge. The water is first pumped into a flume 3 feet by 18 feet by 40 feet long, and then is delivered into the canals. The main canal is 12 miles long and 120 feet wide, and there are 16 miles of laterals 100 feet wide. The fuel used is mesquite wood.

AREA DEVOTED TO RICE CULTURE, BY COUNTIES.

	Acres.		Acres.
Jefferson	44,380	Cameron	3,000
Matagorda	35,460	Victoria	2,770
Wharton	23,600	Austin	1,220
Liberty	16,200	Galveston	800
Colorado	11,450	Washington	780
Orange	10,850	Dewitt	750
Harris	9,100	Jackson	430
Chambers	9,000	Waller	400
Fort Bend	8,830		
Brazoria	3,150	Total	182,170

PROPOSED PLANTS.

In addition to the systems described above there will be several big plants operating in 1903. The Treadway Canal Company will take its water from the Neches River 8 miles northwest of Beaumont and irrigate land on each side of the Southern Pacific Railroad. It is contemplated to bring 25,000 acres in cultivation by this canal. The canals are already under construction.

The Texas Land and Irrigation Company is installing a plant to take its water from the Brazos River northeast of Wallis. Its canal, already under construction, will extend in a southerly direction, and it is intended to bring the land between Wallis, Rosenberg, and East Bernard under canal.

The Illinois Irrigation Company proposes to take out a canal from the Brazos River north of Sealy, near San Felipe, and irrigate lands north and south of Sealy.

The San Jacinto Rice and Irrigation Company expects to put in a plant on the San Jacinto River east of Houston in 1903.

The Wallace-Radford Company intends to irrigate lands east of Eagle Lake by a canal system to take water from Colorado River.

APPENDIX.

The following statement of the Texas laws pertaining to irrigation was prepared by Judge John C. Townes, professor of law in the University of Texas:

A water course, as the words are used in this connection, has been defined as "a stream usually flowing in a particular direction, though it need not flow continually. It may sometimes be dry. It must flow in a definite channel having a a bed, sides, or banks, and usually discharges itself into some other stream or body of water." 27 WIS., 661. COOLEY TORTS, 238.

It will be observed that the water supply need not be sufficient to cause the stream to flow all the time. It must flow habitually, though not necessarily uninterruptedly. There must be a definite channel; that is, a bed or place where the water passes along over the same depression or lower surface, which is bounded or limited by ascertained and definite sides or banks. When these things occur, the water thus confined and seeking a regular outlet is a water course or stream. Water standing in a depression and not flowing is not a stream. Water flowing not in a defined channel, as surface water after a rain, is not a stream. In our changeable climate it is sometimes difficult to determine the question as a fact regarding any particular body of water. Sometimes there is a well-defined channel, but no water except immediately after rains; again there are channels down which water flows frequently, but not continuously. How often it is to run and how long during the year must be answered from the facts in each case. If there is a well-defined channel down which water passes usually—habitually—it is enough, though it may sometimes be dry. If, however, it is usually dry, with water flowing in it only occasionally, it is not a stream.

The water passing in these streams is not owned by anyone. The proprietors of the land crossed by or bordering on the stream have legal rights in its use, but have no property in the water itself. These rights, like all others, have their correlative duties, and the proprietors of the several estates must have regard at all times to the obligations under which each rests toward the other. All persons who own land along a stream are coproprietors in its use. These uses are of two kinds—domestic or natural on the one hand, and artificial or commercial on the other hand. As to the first, the right of use is very extensive, and the proprietor who first gets access to the water lawfully may completely exhaust it in these natural or domestic uses without incurring liability in so doing. It is not so with the second—the artificial or commercial use. Here no one has an exclusive privilege. The upper proprietor can use it for these purposes provided that after this use he permits it to leave his land at the same place, in the same quantity, and of the same quality that it would have but for such use.

It is apparent that the rights and liabilities of the parties vary greatly as the use made of the water is of the one or the other class. It therefore becomes important to understand what uses fall in each class. Domestic or natural purposes embrace drinking purposes for one's family and his own domestic animals, culinary purposes, and washing, and all the uses about one's premises necessary

to sustain life. Artificial or commercial uses are all those in which water is not used directly to sustain life or to give comfort, but is a means of pecuniary profit or indirect means of comfort. This seems to be the line of separation. It works out different results in different localities. It seems to be considered everywhere that the uses mentioned under the head of domestic purposes are such, and that for any of these purposes the upper proprietor or the one first getting lawful access to the water may use it to the entire exhaustion of the supply.

The following are the decisions of the supreme court of Texas:

FLEMING *v.* DAVIS, 37 TEX., 173; APPEAL FROM SAN SABA COUNTY, 1872.

Syllabus 2.—Irrigation of land, however beneficial in some portions of this State, is not one of the natural wants which will justify the owner of a head spring in exhausting the water which flows from it, to the injury of proprietors lower down on the natural channel of the stream. The maxim *sic utere tuo ut alienum non loedas* applies. The case of Tolle *v.* Correth, 31 Tex., 362, is not understood to have decided a contrary doctrine.

Syllabus 3.—In the distribution of the water of a natural stream among the riparian proprietors the principles of the common law furnish the only rules judicially known in this State; and a suit, it seems, can not be sustained to partition a natural stream among riparian proprietors by allotting to each a specified time to appropriate its waters.

BAKER *v.* BROWN, 55 TEX., 377; APPEAL FROM SAN SABA COUNTY, 1881.

Syllabus 1.—The right to use water for purposes of irrigation, when its use is not indispensable, but is resorted to for the purpose of increasing the products of the soil, must be subordinate to the right of a coproprietor to supply his natural wants and those of his family, tenants, and stock, by using the water for necessary and domestic purposes.

Syllabus 2: Limitations; riparian rights.—The rights of a riparian proprietor to the use of the water may be restricted or lost by grant or by prescription, under such adverse, continuous, uninterrupted user and occupation by another as would, by analogy to the statute of limitations, bar the right of entry upon lands. Ten years' use and occupation would in Texas be the period of prescription.

MUD CREEK IRRIGATION CO. *v.* VIVIAN, 74 TEX., 171; APPEAL FROM KINNEY COUNTY, 1889.

Syllabus 1: Irrigation corporations.—An irrigation company chartered under general law and whose charter designates the locality of its canals acquires thereby no exclusive right to the use of the waters of a flowing stream on which it depends for its supply. By virtue of the charter of its incorporation, which authorized the acquisition by gift, purchase, or condemnation of all property necessary to the irrigation enterprise, it secured the right to obtain in the manner designated the privilege of using the water of a stream, but the charter did not *proprio vigore* confer that right in the absence of a purchase, gift, or condemnation.

Syllabus 2: Constitutional law.—The legislature can not destroy or impair the vested rights of a riparian proprietor by conferring a special privilege on an irrigation company without providing for the payment of a just compensation.

Syllabus 3: Riparian proprietors; irrigation cases reviewed.—Tolle *v.* Correth, 31 Tex., 365, and Fleming *v.* Davis, 37 Tex., 173, reviewed, and the doctrine announced that a riparian proprietor has the right to divert water flowing along or through his land to purposes of irrigation, although the effect of such use is to leave to a riparian proprietor on the stream below him a supply of water insufficient for irrigation. No opinion is expressed as to whether water can be used by a riparian proprietor for irrigation so as to render insufficient the supply for ordinary use to those owning land lower down the stream.

Syllabus 4: Prescription.—A prescriptive right to use water for irrigation will be acquired by the uninterrupted use of the water for such purpose under a claim of right. But this right can only be enforced against riparian proprietors on the stream below when the water has been continuously used for ten years under a claim of right. It can not be asserted against a riparian proprietor by or through whose land the water flowed before it reached the point below where it is appropriated by the one claiming the prescriptive right.

Syllabus 5: Presumption of grant.—The presumption of a grant from long continued enjoyment can exist only as against those who might have prevented or interrupted the use of the subject of the supposed grant.

In rendering the opinion in this case, Judge Gaines said:

"It is true that the act of March 10, 1875, provides that 'any * * * canal company shall have the free use of the waters and streams of the State,' but the provisions of that act applied as well to ordinary companies as to corporations. Laws, 2d sess., 14th Leg., 77. Besides, we are of the opinion that the provision could be held only to apply to streams upon the public lands of the State, since the legislature had no power to take away or impair the vested rights of riparian owners without providing for the payment of a just compensation. If the defendants or the owners of the land along the stream in controversy had the right to use the water for the purpose of irrigating their lands, that right remained unaffected by the plaintiff's incorporation or by the legislation of the State passed for the encouragement of irrigation. It seems to be the rule of the common law that a riparian owner has no right to use the water of the stream for irrigating his lands, provided it interferes with the uses of the water by those who own the lands upon the stream below. That this is a proper rule in England and in those States where the rainfall is sufficient for the purposes of agriculture we freely concede, but we are of opinion that in those sections where irrigation is necessary to the successful pursuit of farming it should not apply. What is not a necessary use in the one case becomes necessary in the other. Evans *v.* Merriweather, 3 Scam. (Ill.), 496. It was so held in Tolle *v.* Correth, 31 Texas, 365, and though this decision was criticised in the subsequent case, Fleming *v.* Davis, 37 Texas, 173, we are of the opinion that it recognizes a correct rule of law as applied to the present case.

"We think it a matter of common knowledge that there are portions of our State where the business of agriculture can not be successfully prosecuted through successive years except by irrigation, and it is to be inferred from the allegations of the petition that the section where the stream in controversy is situated is of that character. We think, therefore, that the defendants had the right to divert the water which flowed in the stream along or through their lands for the purpose of irrigating them, although the effect of such use was to leave the plaintiff corporation an insufficient supply for the same purpose. Whether they had the right to divert the whole of it and leave an insufficient supply for the ordinary use of the lower riparian owners we need not in this case determine."

From these cases it is clear that the purposes named above as domestic are regarded as such in this State, and that irrigation ordinarily is not such a use, but that if in any particular locality the business of agriculture can not be successfully prosecuted through successive years except by irrigation, such use in such locality may be regarded as domestic, in a qualified sense; that is, so far as to give the right to so use the water, even though it may deprive lower proprietors of the opportunity of similar use, though this can not be done to the extent of cutting off the supply for drinking water, household purposes, or for stock.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEWAGE POLLUTION

IN THE

METROPOLITAN AREA

NEAR NEW YORK CITY

AND

ITS EFFECT ON INLAND WATER RESOURCES

BY

MARSHALL ORA LEIGHTON

WASHINGTON

GOVERNMENT PRINTING OFFICE

1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 24, 1902.

SIR: I have the honor to transmit herewith a manuscript by Mr. Marshall O. Leighton, relating to sewage pollution in the metropolitan area, and to request that it be published in the series of Water-Supply and Irrigation Papers. In an investigation of the water resources of the country it becomes necessary in the thickly settled portions to give consideration not merely to the quantity of water and its fluctuations, but also to the quality, and to the changes that are taking place owing to the presence of various industries.

The best methods of utilizing the water resources of the country are dependent not only upon geologic and topographic features, but also upon what has been termed cultural conditions, the latter embracing all of the changes brought about by man. The accompanying discussion by Mr. Leighton relates to a portion of the most thickly settled part of the United States, and shows that water resources may be so misused that streams which in their natural condition were useful and attractive may be rendered obnoxious and made sources of loss to the community.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEWAGE POLLUTION IN THE METROPOLITAN AREA NEAR NEW YORK CITY AND ITS EFFECT ON INLAND WATER RESOURCES.

By MARSHALL O. LEIGHTON.

NORMAL WATERS.

In a primeval country, undisturbed by the advance of civilization, where there are no houses, barns, or factories, the water that flows from a drainage basin may be said to be normal. This, however, does not mean that the water is chemically pure. The water of precipitation or rainfall, which is the origin of all surface waters, takes three courses, the proportion carried along each depending upon many physical characters and conditions. There is, first, that which is evaporated or absorbed by vegetation; second, that which runs off the ground directly into water courses; and third, that which sinks into the ground and reappears in various well-known ways after having filtered through the earth.

The character of the water is markedly influenced by the ingredients which it takes up along these courses, and therefore chemically pure water is seldom found in nature. Water that runs along the earth's surface directly into natural water courses carries in suspension a large quantity of fine particles which lie in its way—vegetable matter in a state of complete disintegration, organic matter in various stages of oxidation, minute particles of sand and mineral matter from the earth, and large quantities of silt. On the other hand, water that sinks into the ground leaves behind, in the majority of cases, these suspended particles, but when it reappears it carries in solution the soluble mineral constituents of the earth through which it has passed, and, if it then contains any dissolved organic matter it is usually in an advanced state of oxidation. Water thus discharged from drainage areas is by no means uniform in composition, nor is it of the same nature in the same area during a series of examinations. Run-off water varies in character according to the amount of precipitation, the

season of the year and consequent state of vegetation, the extremes of temperature, the nature and slope of the surface of the land, and many other physical conditions, varying familiarly from season to season. During the season of copious rains it is observed that water from a drainage area carries along more sediment than during seasons of normal precipitation, and analysis would show that the organic matter contained in the water is in larger proportion. At the close of the warm season, during which vegetation has been flourishing, there is much less decayed and dried vegetable matter to be carried along than during the spring season, after the winter has destroyed the tender growth of the previous summer. Again, during the warm season there is a larger proportion of precipitation absorbed by vegetation and evaporated. The season is also a factor in determining the condition of water in countries in which snow covers the ground for a part of the year. During the time of snow the water which during warm seasons would be immediately diverted to its accustomed channels is retained upon the surface of the earth, to be evaporated by prevailing winds or to be melted quickly upon the approach of spring.

The slope and the nature of the surface of the land are important factors in determining the character of surface waters. Where surfaces are steep and smooth a large proportion of water runs directly into streams, and with it a great amount of sediment, while upon most flat surfaces nearly all the precipitation not directly evaporated sinks into the ground. Between the steep, smooth surfaces and the flat ones there are many gradations, each having its effect upon the final content of run-off water.

Distance from the ocean is another factor influencing the character of water. This has been the subject of an extended series of investigations by the Massachusetts State board of health, and later by other bodies, both corporate and private. It is found that the amount of chlorine is highest at coast points, and as we recede farther and farther inland the proportion in normal waters grows correspondingly smaller, so that it is possible to trace upon the map of a country the lines of uniform normal chlorine in much the same manner that lines of equal altitude are traced upon a topographic map.

The state of preservation of the forests of a country exerts an influence of great importance upon the character of surface waters and upon the flow of streams. In the absence of trees there is less absorption of rain water by the ground and a correspondingly larger proportion is carried directly into the water courses with a greater amount of sediment, so that a drainage area that has been largely denuded of trees is subject to greater variation of stream flow and more frequent freshets than is an area that is in large part covered by forests. On denuded areas there is less evaporation, and ultimately the whole character of the surface may be so changed by loss

of vegetation and extensive erosion that the immediate run-off water may comprise almost the entire precipitation.

Having reviewed the more important conditions and influences that affect the character of normal water, let us consider the economic value of water to the community. Intercepted and stored in reservoirs it has become indispensable to large communities for domestic and manufacturing uses; from prehistoric times large rivers have been used as avenues of transportation; as motive power water has been used for ages; vast harvests of ice are gathered from the surface of Northern rivers; in arid countries water finds extensive use in irrigation; it may be the source of food supply through fisheries, and its presence in a country is valuable from a purely æsthetic point of view, lakes and fountains forming a natural nucleus for parks, resorts, and places of rest and recreation.

POLLUTED WATERS.

When, however, man makes his abode in any area and carries on his normal life, the water draining that area soon assumes characters which it had hitherto not possessed. It now contains the products of excretions of man and of the domestic animals that accompany him, and the amount of change in the character of the water depends entirely upon the number of people and their pursuits. In the beginning pollution is indirect, but with social and commercial progress come modern improvements, and eventually the public sewer is laid to the nearest and most convenient body of water. This is the natural course, and in inland municipalities there may be developed in the course of time a system of sewerage conducting such a volume of city waste that the largest river on the globe can not dilute it sufficiently to disguise its presence. Let us consider briefly whether water so polluted can be applied to all of the uses to which normal waters have been found applicable.

Many American cities have been taught by dear experience that it is fatal to provide polluted waters for household purposes. Lowell and Lawrence, Newark and Jersey City, Albany, Pittsburg, Louisville, Cincinnati, and many other cities have profited by that experience. Philadelphia has just shaken off the lethargy of decades and is now preparing to filter the refuse of municipalities on the upper Schuylkill and Delaware. Other cities have their lesson yet to learn, but each will probably learn it only when its group of mourners has become large enough to demand attention. With childlike faith the city of Albany, reassured by the advice of an eminent chemist, established its water intake in the cesspool of the Hudson. Yet after a few years, during which many lives were lost in the ravages of waterborne disease, it constructed one of the most extensive filters in the

country, at a cost of half a million dollars. He who says that a polluted river will purify itself in the course of several miles reckons with an unknown force which will probably fail him at the critical time.

The same conditions and statements apply to ice. Although recent work seems to show that the germs of typhoid fever do not remain intact in ice as long as was formerly supposed, there is yet but little evidence obtained concerning the bacteria of other water-borne diseases. Irrespective of disease organisms, the use of ice from polluted waters in our houses and markets is abhorrent and will not be tolerated.

As a rule, the presence of pollution in water used for irrigation is not a detriment. On the contrary, it may be an aid to vegetation, although the manurial value of sewage is not so great as is popularly supposed.

The use of water for power is not usually affected by pollution, although in some cases mill ponds have become grievous nuisances on account of the storage of pollution from a municipality above. In certain kinds of manufacturing, however, pure water must be used, and in such cases the use of polluted water from a neighboring stream is prohibited, so that an added expense is necessitated for another supply and the value of the near-by stream is diminished.

A single stream very seldom—almost never—embraces all of the uses enumerated above. If the waters are navigable to any extent there can be no power sites, nor can the "raw" water be used for public supply, and only seldom is the ice which it bears a wholesome product. If, on the other hand, waters are to be conserved for power or for public supply, it will be impossible to use them for traffic. If a stream which is not navigable is polluted, it may be, if the pollution be extensive, that the water will be rendered unfit for any purpose whatever; for, transportation or ice cutting being precluded by the physical conditions, we have only irrigation, power, and public supply remaining. Of these three the last may be entirely cut off, the second may be modified, and only the first may remain practically intact. As irrigation is important only in the dry areas of the West, this asset does not apply in the remainder of the country, and so we find that in many cases the entire value of a stream may be lost through pollution.

Extensive pollution unfits a river for a nucleus for park areas. Deposits of filth upon the banks of streams make noxious odors and render such places undesirable as dwelling sites. The value of property is impaired, the neighborhood is shorn of desirable population, and places that were once fair to look upon may become, by reason of sewage pollution, famous only for foul odors and unpleasant associations.

The consideration of such matters is very familiar in treatises on

questions involving public health. It has been conceded that, from a general hygienic standpoint, no stream should be polluted with sewage. It is, however, the purpose of this paper to consider the matter from a standpoint of diminution of natural resources with special reference to the rivers in "the metropolitan area," comprising northern New Jersey, southern New York, and the western part of Massachusetts. It is proposed to take into account the water resources of this section and to show, as closely as available information will permit, the loss which has come about by reason of river pollution. This part of the United States has become the metropolitan area chiefly because of its natural resources, both maritime and inland. Among these sources of economic supremacy the value of the inland waters stands in the front rank.

The consideration of financial loss due to sewage pollution of streams in this area becomes, therefore, of immediate importance; and as we shall enumerate in the following pages the expenditures made necessary by this discredited practice, it is possible that we shall find sewage pollution not only an agency most destructive to human life, but one of the most far-reaching drains upon human wealth that has yet been considered. In addition to the mere question of existing pollution there is the problem of abatement or prevention, which is receiving consideration in many States under authority granted by legislative enactment. This method of consideration may serve admirably in the several States, but what of interstate pollution? State boundaries in the eastern part of this country are so closely set that instances of interstate grievance are numerous. A municipality made miserable by polluted water from another State is deplorably helpless to obtain remedy. There is no national authority over such matters.

RARITAN RIVER.

The Raritan River is the largest in New Jersey, and the second in economic importance. The drainage area—1,105 square miles in extent—is of a mixed type, having 275 square miles of highland area, 100 square miles of sandy plain, and the remainder of red sandstone. Budd Lake, 1½ miles long and three-quarters of a mile wide, is the only extensive storage reservoir in the basin. Only about 13 per cent of the area is in forest, and the bareness of vegetation, in connection with the limited storage facilities and the extensive steep trap-rock surfaces, causes an excessive flood flow, which at times does a large amount of damage. The river is navigable to New Brunswick, 10 miles from the mouth, and is affected by tides to a point 4 miles higher. Records of gagings have been maintained since the year 1890 at the Delaware and Raritan Canal dam, 15 miles above the mouth of the river. In the report of the Geological Survey of New Jersey (Vol. III, p. 209) there appears a flow table

computed from these gagings, covering the years 1890–1893, inclusive, as follows:

TABLE I.—*Flow of the Raritan at Bound Brook, 1890–1893.*

[Drainage area, 879 square miles.]

Month.	Rain.	Flow.	Flow in second-feet.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February 17 to 28	1.58	0.98	2,772	1,406	1,938
March	6.26	6.13	17,818	872	4,727
April	2.74	2.26	3,265	874	1,773
May	4.95	1.96	4,060	752	1,489
June	3.97	1.32	2,824	426	1,040
July	5.68	1.18	2,022	498	898
August	5.18	1.58	3,405	498	1,205
September	4.13	1.34	2,823	493	1,064
October	6.74	3.06	7,183	859	2,360
November	.88	1.30	1,779	781	1,016
December	3.55	2.16	7,526	462	1,654
1891.					
January	7.06	4.92	23,746	420	3,738
February	4.21	3.47	6,056	1,295	2,931
March	4.64	4.47	10,142	1,386	3,404
April	1.83	1.62	3,439	512	1,276
May	2.70	.59	735	245	450
June	1.75	.24	509	113	189
July	3.92	.28	326	180	213
August	6.58	.94	5,804	148	716
September	1.72	.86	2,564	253	687
October	2.68	.43	804	208	328
November	2.21	.54	1,174	201	426
December	4.74	2.36	8,215	292	1,798
1892.					
January	5.58	4.57	22,760	990	3,482
February	1.19	1.31	5,182	720	1,066
March	3.98	2.59	7,941	796	1,974
April	2.02	1.25	1,893	677	995
May	4.62	1.47	3,177	513	1,120
June	4.06	1.60	10,927	443	1,261
July	4.11	.57	2,764	180	434
August	3.61	.47	2,201	180	358
September	2.75	.31	711	180	244
October	.32	.24	201	122	183
November	6.99	2.18	20,698	122	1,718
December	1.68	1.29	2,610	609	983
1893.					
January	3.39	2.11	12,514	720	1,608
February	6.23	4.16	15,772	1,228	3,494
March	3.14	5.27	19,125	878	4,016
April	4.65	4.00	10,091	918	3,152
May	4.28	3.30	10,987	387	1,515
June	3.57	.64	2,130	180	504
July	3.14	.43	820	180	328
August	8.27	1.45	5,893	180	1,105
September	3.60	.71	3,284	157	559
October	3.86	.95	4,494	180	724
November	3.59	1.50	7,352	291	1,190
December	3.12	2.63	2,698	180	2,004

As a source of water power the Raritan River is not so important as the size of the drainage area and the fall of the river would indicate. The tributaries are widely divergent, and do not, as in the most valuable power streams, join in a common course at any considerable distance above the mouth of the river. In this case the important branches of the system are not united until they arrive at a point within 7 miles from the head of tide water and even then at an elevation of only 17 feet. The largest developed power is at High Bridge,

on the South Branch. The extreme floods above mentioned occur frequently, unfitting the basin for any large development of power.

It would seem, upon first consideration, that the Raritan River is not especially valuable as a source of water supply. In quick-spilling basins large amounts of suspended matter are brought down, and in this river there is nearly always apparent a varying amount of red mud. Upon settlement, however, the water is suitable for public use, and there is no reason why excellent water supplies could not be derived from this stream by proper management; but up to the present time the river has been very little utilized for this purpose.

TRIBUTARIES OF THE RARITAN.

SOUTH RIVER.

This river rises in or near Freehold Township, at a point 20 miles due south from where it empties into the Raritan at Sayreville. The flow is much more steady than that of any other branch of the system, and this has led to an extensive use of the stream as a source of power. No large water supply can well be conserved in this drainage area. At the present time, it is true, the city of Perth Amboy derives its water from Tennent Brook, a tributary of South River, but the daily consumption amounts to practically the normal yield of the watershed. It would be possible, by carefully selecting sites for small reservoirs, to conserve several small supplies which, when combined, would be of considerable value.

NORTH BRANCH OF THE RARITAN.

The drainage area of North Branch occupies 191.6 square miles, in the northernmost portion of the Raritan Basin. It is sharply divided into the highland area and red sandstone plain, the former occupying the greater part of the country tributary to this branch. It lies at an elevation of 800 to 1,100 feet, 30 per cent of which is in forest. The population averages 72 per square mile. The red sandstone plain has an elevation of from 200 to 300 feet.

Mr. C. C. Vermeule, author of the report of the Geological Survey of New Jersey above referred to, estimates that there are 7.8 horsepower per foot of fall at the mouth of North Branch. In the entire tributary there are developed 1,052 horsepower at 46 sites.

There are many possibilities for developing excellent water supplies in the basin of the North Branch. Mr. Vermeule states that on the Lamington River, which is the main affluent of the tributary, there is an area of 31.4 square miles above the 500-foot contour which can be developed to yield 21,000,000 gallons daily. Similarly on the North Branch, above the junction of Peapack Brook, there is a drainage area of 29.1 square miles, from which may be derived 19,000,000 gallons a day. At other points in the basin there may be economically gathered a total of about 20,000,000 gallons daily.

SOUTH BRANCH OF THE RARITAN.

This branch drains 276.5 square miles of territory, which is divided into the highland area and red sandstone plain, like that on the North Branch. In this case, however, the plain occupies the larger part of the basin, with an average elevation of about 400 feet. Budd Lake, already described, lies at the head of the South Branch.

As a source of water power South Branch has been rather extensively developed. At 67 sites there is developed a total net horsepower of 2,681.

As a source of water supply the entire basin has a capacity of nearly 100,000,000 gallons daily, with 7 inches storage. Budd Lake has a watershed of 4.5 square miles, is at an elevation of 933 feet, and affords a pondage which will supply 3,000,000 gallons daily.

POLLUTION IN RARITAN RIVER.

The country included in the drainage basin of the Raritan has not yet been sufficiently developed to be damaged to any great extent by sewage, except possibly in the lower part. On the highland tributaries there are few important towns, and the character of the water is not affected to any great degree by pollution. The first city above the mouth of the Raritan is New Brunswick, which has a population of 20,006. The river at this point is tidal and within the limit of salt-water influence. Damage done by pollution can therefore be only that which arises from the general nuisance accompanying the discharge of sewage.

A few miles above New Brunswick is Bound Brook, a borough of 2,622 inhabitants, while farther on are Somerville and Raritan, towns of 4,843 and 3,244 inhabitants, respectively. These three places contribute a certain amount of pollution, which, while it does not do any appreciable damage to the general resources of the river, certainly unfits it for use as a source of water supply without filtration.

Above Raritan there are numerous small villages of a few hundred inhabitants, but all of these are unimportant as agencies of pollution.

The Raritan River, in spite of its proximity to the metropolis of the United States, strangely enough, presents a fairly clean record as to pollution except in a limited area about the mouth of the stream. It is thus notable, especially when contrasted with other rivers in this part of the country, and the contrast shows in a striking manner the difference between water resources yet unimpaired and those which have been injured or destroyed by careless and inconsiderate municipal management. In this case we find that in the majority of tributaries the water flowing out of the Raritan Basin is fit for immediate use in a public supply. The water powers developed have not been reduced in value by reason of any nuisance arising from the concentration of municipal sewage behind the various milldams. Fish-

eries have been preserved intact. The ice, as far as it is harvested, is above reproach, and the whole country is available for economic development. Let us see how it appears in the case of a river draining the country immediately adjoining.

PASSAIC RIVER.

By far the most valuable drainage system in New Jersey is that of the Passaic. It comprises a territory of 941.1 square miles, in which are situated the drainage areas of the Passaic proper (including the upper and lower valleys), the Saddle, Ramapo, and Wanaque rivers, which extend into New York State on the north, and the Pequanac, Rockaway, and Whippany on the west. Within this territory there are said to be 8 square miles of lakes and 26 square miles of swamp land.

The Passaic River rises in Morris County, in a region adjacent to that from which the North Branch of the Raritan is derived. Its course is exceedingly irregular, passing in or adjacent to six counties before finally reaching Newark Bay. The distance from source to

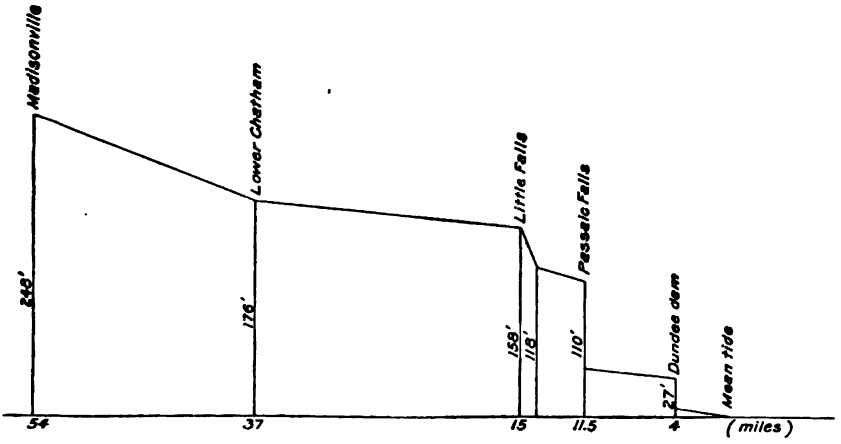

FIG. 1.—Profile of Passaic River.

mouth in a direct line is about 25 miles, while the river measures somewhat over 80 miles in its course.

The profile of the river is interesting and shows clearly the amount of power available in the lower valley. Tide influence extends about 13 miles above the mouth of the river, to a point nearly opposite Passaic. Commerce is developed extensively at Newark, and the river is navigable to the head of tide water. Four miles above this point is Dundee dam (see Pl. III, *A*), the lowest power site in the main river. Above it is a drainage area of 822.4 square miles. The fall is 22 feet, and the net horsepower developed is 1,235. The elevation of the crest of Dundee dam is 27 feet above mean tide. From this point there is a rise of 13 feet in 7.5 miles to the foot of the Great

Falls of the Passaic (see Pl. I, *B*), an imposing cataract, sheer 70 feet in height. In a distance of 4 miles, from the top of Great Falls to the foot of Little Falls, there is a rise of 8 feet. The series of falls and rapids at Little Falls, together with the height of the dam at the crest, make a total rise of 40 feet. This point is the head of power on the main river; it marks the boundary between the middle and lower valleys of the Passaic, uniting the drainage from an area of 772.9 square miles. The elevation is about 158 feet above mean tide, and the distance from tide water is only 15 miles.

At Two Bridges, a short distance above Little Falls, Pompton River enters the Passaic. Above Two Bridges the Passaic follows a winding channel 22 miles long, through a large meadow area, until at Chatham, at an altitude 6 feet above Two Bridges, the bed takes a sharper grade. From this point to the source of the stream, a distance of 18 miles, there is a rise of 72 feet.

The resources of the river that are developed most completely in the lower valley of the main stream are considered in detail in Vol. III of the report of the Geological Survey of New Jersey and in the report of the Tenth Census (Vol. XVI, pp. 647–652), so that only a general description will be given here. From mean tide up to the crest of Little Falls, 102 feet is developed and only 25 feet of the remainder is available for development. The Dundee dam is 450 feet long and impounds a lake of 224 acres, diverting the entire flow of the river in dry seasons. There is here a continuous horsepower during nine months of the year of 36.18 per foot fall, which, when used ten hours a day, allows the Dundee Water Power and Land Company to rent 1,764 horsepower. The fall of the stream has been carefully recorded at this point since 1877, and the results of the record are given in Tables II and III. These are compiled from a diagram in the report of the New Jersey geological survey above referred to.

TABLE II.—*Daily flow of Passaic River at Paterson and Dundee.*

[Inches on watershed.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average.
1877	0.029	0.081	0.202	0.107	0.032	0.021	0.015	0.015	0.013	0.096	0.164	0.081	0.071
1878	.084	.138	.126	.046	.055	.054	.027	.053	.018	.019	.058	.237	.076
1879	.027	.071	.182	.143	.055	.034	.035	.051	.081	.010	.012	.075	.061
1880	.115	.092	.080	.090	.036	.012	.013	.....	.012	.011	.027	.021	.041
1881	.037	.131	.215	.042	.029	.056	.037	.010	.010	.010	.018	.052	.054
1882	.069	.171	.127	.117	.105	.061	.061	.018	.197	.043	.019	.038	.094
1883	.031	.115	.106	.098	.053	.024	.033	.013	.013	.047	.044	.024	.050
1884	.092	.215	.157	.094	.067	.022	.043	.030	.010	.019	.035	.011	.066
1885	.137	.081	.066	.115	.054	.016	.015	.026	.010	.027	.089	.102	.063
1886	.109	.189	.097	.114	.113	.034	.017	.018	.010	.018	.032	.037	.066
1887	.105	.171	.118	.087	.039	.069	.080	.052	.014	.027	.021	.109	.074
1888	.145	.138	.166	.195	.024	.014	.013	.034	.160	.015	.105	.138	.096
1889	.192	.087	.104	.137	.104	.059	.088	.145	.142	.055	.215	.148	.123
1890	.066	.118	.107	.099	.087	.051	.031	.035	.151	.084	.047	.051	.077
1891	.192	.205	.169	.076	.029	.015	.014	.023	.023	.012	.026	.065	.071
1892	.158	.052	.035	.054	.045	.038	.019	.019	.014	.011	.048	.039	.046
1893	.121	.203	.227	.130	.155	.077	.025	.023	.020	.041	.....	.056	.098
Monthly average	.101	.133	.136	.099	.064	.039	.033	.035	.050	.032	.067	.070	.....

A. ALONG THE PASSAIC BELOW PATERSON.

B. GREAT FALLS OF THE PASSAIC AT PATERSON, N. J.

TABLE III.—*Daily flow of Passaic River at Paterson and Dundee.*

[Cubic feet per second.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average.
1877	640	1,190	4,467	2,365	706	464	330	330	286	2,123	3,924	1,790	1,570
1878	1,856	3,049	2,785	1,014	1,215	1,193	596	1,171	396	418	1,281	5,239	1,680
1879	596	1,567	4,022	3,159	1,215	750	772	1,127	684	220	262	1,658	1,347
1880	2,541	2,032	1,768	662	794	264	286	.....	264	242	596	464	907
1881	816	2,895	4,753	926	640	1,237	816	220	220	220	396	1,149	1,193
1882	1,523	4,078	2,807	2,585	2,321	1,347	1,347	396	4,357	1,051	418	838	2,079
1883	684	2,541	2,343	2,164	1,171	530	728	286	286	1,039	973	530	1,105
1884	2,032	4,753	3,770	2,076	1,479	486	951	662	220	418	772	242	1,457
1885	3,027	1,790	1,457	2,541	1,193	252	330	574	220	596	1,996	2,255	1,391
1886	2,409	4,176	2,142	2,519	2,497	750	374	396	220	396	706	816	1,457
1887	2,321	4,078	2,607	1,922	800	1,516	1,768	1,149	308	596	464	2,469	1,636
1888	3,203	3,049	3,968	4,308	530	308	286	750	3,836	330	2,321	2,949	2,123
1889	4,242	1,922	2,299	3,027	2,259	1,304	1,944	3,506	3,440	1,215	4,753	3,572	2,719
1890	1,357	2,607	2,365	2,186	1,922	1,127	684	772	3,638	1,856	1,039	1,127	1,702
1891	4,242	4,533	4,034	1,680	640	330	308	508	508	264	574	1,435	1,570
1892	3,792	596	1,435	1,193	995	838	420	420	308	242	1,061	860	1,017
1893	2,673	4,489	5,019	2,873	3,726	1,702	552	508	442	907	.....	1,237	2,167
Monthly average	2,233	2,939	3,005	2,186	1,413	880	728	772	1,105	708	1,479	1,548	.....

Concerning the methods of observation and accuracy of the determinations set down in Tables II and III, Mr. C. C. Vermeule, author of the report, says:

We have, by the courtesy of several users of water power, been able to obtain measurements of flow covering a period of seventeen years and a very wide range of rainfall conditions, from 70.88 to 37.03 annually. These gagings were at Little Falls and points below, and have been reduced, compared, and adjusted, two series being for several years contemporaneous. The results we have much confidence in. They are consistent, and bear the test of close analysis as well as any series of gagings we have made.

Table II gives the average daily flow in inches upon the watershed for each month of the period 1877–1893, and also the daily flow for each year and the monthly averages for the whole term. Table III gives similar information, except that it is expressed in terms of cubic feet per second actually flowing through the channel.

The power site at Great Falls, Paterson, is one of the oldest large water powers in the United States. Above the head of the falls is a low stone dam, affording, however, sufficient pondage to concentrate the entire dry season flow into working hours. The Society for Establishing Useful Manufactures, which controls this power, receives about $36 per gross horsepower per annum for about 2,300 horsepower, but the dry-weather flow does not supply more than half of this, and the power is not, therefore, guaranteed. The conservance of water from the upper Pequanac area for the city of Newark and the large drafts upon the river at Little Falls for the supply of Paterson, Passaic, and Jersey City have increased the uncertainty of the power at this place. The Rockaway area is now being set apart

for the use of Jersey City, and it is expected that the constantly increasing demands of the water-supply interests will soon bring the power values to a very low basis. The power, both at Dundee and Great Falls, has passed into the control of the New Jersey General Security Company, a corporation closely allied to the East Jersey Water Company, and the contest between power and water-supply interests which was at one time probable has been averted.

At Little Falls about 450 horsepower was developed, but it has been greatly reduced by the lowering of the dam for the purpose of draining the Great Piece Meadows, a wide area over which the water stands for days during freshets. The actual power value is therefore not great. Since the assumption of control by the East Jersey Water Company, the necessity for greater pondage has not been evident, sufficient being necessary to properly flood the water intake only. This intake is located on the north side of the river, a little above and at a short distance from the dam. Above the meadows the power sites on the main stream are not of great importance.

This stream forms a nucleus for a water supply which in capacity and quality can not be excelled in the metropolitan district, and from the manner in which it is now being developed it is probable that at no distant date that part of the river between Little Falls and Passaic will lose much of its value as a source of power.

TRIBUTARIES OF THE PASSAIC.

The Pompton River, which joins the Passaic at Two Bridges, above Little Falls, combines the flow of the Ramapo, Wanaque, and Pequanac, representing a combined area of 379.9 square miles. Through the Great Piece Meadows flows Rockaway River, draining 138.4 square miles, and farther up the Whippany, draining 71.1 square miles. Each of these areas forms by itself a gathering ground from all of which, except the latter, can be diverted water supplies equal to almost any emergency which the great cities of northern New Jersey are likely to encounter during the next century. The Rockaway and Pequanac, as stated above, have already been claimed. The Ramapo is now under the control of a New York corporation, which endeavored to secure a metropolitan monopoly. There remain only the Wanaque, a small available area in the Whippany, and the Upper Passaic for future development. These will be considered, each by itself as a separate stream, after we have examined the Passaic proper as a source of supply.

In spite of the largely diverted drainage of its highland tributaries, the Passaic will always be a valuable source of water supply, for it possesses a large drainage area of itself. Above Little Falls, on the main river, there is at the present time a supply that will afford, without storage, nearly 88,000,000 gallons daily. With the highland

A. GREAT FALLS OF THE PASSAIC AT PATERSON, FROM THE CREST.

B. PASSAIC RIVER BELOW GREAT FALLS AT PATERSON.

tributaries diverted, as they are likely to be in the future, there will still be a drainage area of 208 square miles, affording a supply of approximately 25,000,000 gallons daily, without storage. For years the cities of Newark and Jersey City took water from the river at Belleville, below Passaic, amounting to from 30,000,000 to 40,000,000 gallons daily. The intakes are now out of use, Newark having gone up to the Pequanac area for its water supply and Jersey City to Little Falls temporarily, until the supply from the Rockaway shall have been established. Immediately above Little Falls, on the meadows, there is no good point on the Passaic for a reservoir, and the large area of flat land causes generally muddy and unsatisfactory water. Above this, in the upper Highlands, is an excellent basin, called Great Passaic Swamp, which might easily be set apart as a storage reservoir. The drainage area is small and rather thickly populated, yet the situation remains available and can be used in case of need.

SADDLE RIVER.

This is the lowest and least important branch in the Passiac system. It rises in Rockland County, New York State, flows south for 17 miles and empties into the Passaic about 12 miles from the mouth. The drainage area contains 60.7 square miles, underlain by the red sandstone common to the main basin. It has 8 square miles of drainage area in New York State, and the population, according to the report of the Geological Survey of New Jersey in 1894, was about 122 per square mile. As a source of water power the river is not important. Out of a total fall of 90 feet there have been utilized about 60.5 feet, the power from which is divided into 47 sites along the river, representing a gross horsepower of 1,700. It is fairly good gathering ground for a limited water supply, and might be developed as an auxiliary to be used in an emergency. With a storage of 7.5 feet upon the reservoir it would yield 14,000,000 gallons daily.

RAMAPO RIVER.

Although emptying into the Passaic by way of Pompton River, this stream belongs largely to New York State, as about 70 per cent of the 160.7 square miles of drainage area is located beyond the Jersey limits. About 75 per cent of this area is forested, and the population is approximately 60 per square mile. Gagings of the flow of the river, extending through a period of two years, were made at the works of the Pompton Steel and Iron Company, and are compiled in Table IV, which is taken from the report of the Geological Survey of New Jersey (Vol. III, 1894, p. 168).

TABLE IV.—*Flow of Ramapo River at Pompton.*

[Drainage area, 159.5 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February 7 to 28	4.45	3.29	1,913	277	643
March	6.40	4.85	2,020	277	643
April	2.68	3.05	1,082	281	429
May	4.72	2.75	762	170	377
1890-91.					
June	4.98	1.25	334	55	176
July	6.06	.94	338	40	125
August	4.75	.80	601	41	108
September	4.14	1.51	948	55	209
October	6.95	2.22	839	91	301
November	.77	1.10	320	80	155
December	4.02	1.77	1,583	80	238
January	8.51	6.36	4,552	318	879
February	4.50	5.28	2,130	264	853
March	4.25	5.23	1,686	299	729
April	2.80	2.34	695	143	335
May	2.70	.67	187	41	94
June to May	54.43	29.47			
1891-92.					
June	2.13	.37	79	33	52
July	4.88	.31	70	22	44
August	5.54	.96	536	33	135
September	2.28	.67	318	40	94
October	2.39	.30	53	40	42
November	2.93	1.47	601	33	207
December	4.77	2.78	1,175	104	391
January	5.65	5.65	1,949	267	794
February	1.34	1.19	267	123	167
March	3.65	2.30	662	147	323
April	1.73	1.33	293	117	188
May	4.66	1.83	748	91	258
June to May	41.95	19.16			
1892.					
June	4.07	2.00	1,095	45	281
July	3.37				
August	4.36				
September	1.97				
October	.68	Gagings Oct. 10, 22.5 cubic feet per second.			

At Pompton, 1.5 miles above the confluence of the Ramapo with the Pompton, the Ramapo has a fall of 29 feet. The lake, which is traversed by a 7-foot dam, is about 202 acres in extent. The power developed at this place, as estimated by Mr. Vermeule, is 17.04 horsepower per foot fall. There are many other sites on the watershed which are not yet developed, but none are of great importance. The river has never been a favorite power stream.

In many ways Ramapo River is a favorable gathering ground for a city water supply. The name has, during the past few years, become well known in the metropolitan area by reason of the existence of a water corporation known as the Ramapo Company, which endeavored to acquire, and almost succeeded in obtaining, the most valuable water franchise in America—that of New York City—charging rates which, at the end of the contract period, would involve a loss to the city of New York of about $190,000,000. Although this corporation

A. DUNDEE DAM, WHICH HOLDS BACK AND CONCENTRATES THE SEWAGE FROM PATERSON.

B. DUNDEE CANAL.

controls the water rights on the New York part of the drainage area, this portion was not included as a source of supply in the plan that was presented to the city of New York. The river yields, without storage, at Pompton, 14,500,000 gallons daily. With a storage equal to 7 inches upon the watershed, the available supply would be approximately 120,000,000 gallons daily.

WANAQUE RIVER.

In its general geographic course this stream is not unlike the Ramapo. Greenwood Lake (see Pl. IV, *A*), situated on the line between New York and New Jersey, and extending into New York State about 3 miles, and Sterling Lake, entirely within New York State, afford excellent pondage. Greenwood Lake has an elevation of 621 feet, has 6 square miles of surface, and receives the drainage of 28 square miles. Its storage capacity, according to Croes and Howell, is 134,000,000 gallons, and it will supply 18,000,000 gallons daily throughout the year. Sterling Lake has an area of 321 acres and a watershed of 4.69 square miles. It will supply throughout the year about 3,000,000 gallons daily.

The only series of gagings available for Wanaque River is that made under the direction of the Geological Survey of New Jersey at the dam near Pompton station. These gagings cover a period when the stream is least affected by drafts from Greenwood Lake, and are compiled in Table V.

TABLE V.—*Flow of Wanaque River, 1890–91.*

[Drainage area, 101 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
October	6.95	2.49	594	91	217
November	.77	.93	128	44	84
December	4.02	1.59	799	44	138
1891.					
January	8.51	6.27	4,943	91	549
February	4.50	5.51	1,107	217	548
March	4.25	5.55	914	217	516
April	2.80	1.92	308	92	174
May	2.96	.61	77	45	54
December to May	27.04	21.45	Loss, 5.59 inches.		

On account of the large pondage, the flow of this river could be made comparatively uniform, and the power developed would be of considerable value. At the mouth of the river there are about 10 horsepower per foot fall, a part of which is contributed by Greenwood Lake. Power sites are available in the upper parts of the stream, and the one located in the Ringwood district could be developed to yield a steady horsepower of 2,000 during working hours.

This river forms another excellent source of city supply. It has already been stated that there is a pondage representing the drainage from 33 square miles. For the remaining run-off water there are good sites for conservance, and with a total utilization of 14 inches upon the watershed there would be afforded a supply of 75,000,000 gallons daily. Of the watershed, 28.2 square miles are in New York, and 80 per cent of the entire area is forested.

PEQUANAC RIVER.

Mr. Vermeule, author of the report of the Geological Survey of New Jersey above quoted, describes the Pequanac River as follows (p. 175):

This is another branch of the Passaic, and with the Ramapo and Wanaque forms the Pompton River just below Pompton. Its drainage area lies high on the Archean highlands. For nearly its whole course it flows transversely to the ridge and valley structure of these highlands, thus differing from the Ramapo and Wanaque, which flow through deep valleys. The headwaters of the Pequanac are at an elevation of nearly 1,500 [feet], while the mouth, at Pompton, is only 170, consequently the stream has great fall. From Post's dam at Riverdale, 2 miles above the junction of the Ramapo, to New Foundland, 12.5 miles above, the fall is 45 feet per mile; thence to Wallace's corners it is 9.2 feet per mile for 6.5 miles; for 2 miles above this, to Stockholm, it is 30 feet per mile. The watershed is 6 or 7 miles wide by 16 miles long and the branches are quite uniformly distributed along the course of the main stream, mostly coming in from the northeast. Forests cover 78 per cent of the area.

The flow of the river is compiled in Tables VI and VII, the first of which was made under the direction of the Geological Survey of New Jersey, while the second was made by Mr. Clemens Herschell, chief engineer of the East Jersey Water Company.

TABLE VI.—*Flow of Pequanac River at Riverdale.*

[Drainage area, 84.7 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February	4.45	3.38	686	125	273
March	6.40	4.02	891	155	296
April	2.68	2.70	382	75	205
May 1 to 5	.31	.20	155	74	91
June					
July					
August					
September 27 to 30	.58	.08	90	25	45
October	6.95	3.61	959	25	264
November	.77	1.42	301	25	100
December	4.02	1.03	437	25	75
1891.					
January	8.51	5.17	2,352	48	387
February	4.50	5.05	1,384	46	276
March	4.25	4.12	683	46	192
April	2.80	1.50	234	46	215
May	2.70	.62	77	45	53
December to May	26.78	17.49			

A. GREENWOOD LAKE, HEAD OF WANAQUE RIVER.

B. DAM AT MACOPIN INTAKE, NEWARK WATER SUPPLY

TABLE VII.—*Flow of Pequanac River at Macopin intake.*

[Drainage area, 63.7 square miles.]

Month.	Rain.	Flow.	Average weekly flow in cubic feet per second.		
			Greatest.	Least.	Average.
1891-92.	*Inches.*	*Inches.*			
June	1.76	0.55	48	16	31
July	5.01	.27	20	20	15
August	5.75	1.39	254	16	80
September	1.93	.90	90	25	51
October	2.11	.34	23	15	19
November	3.19	1.73	172	16	97
December	4.99	3.77	415	105	212
January	5.95	5.96	450	173	335
February	.99	1.63	115	72	92
March	4.30	2.58	183	125	145
April	1.43	1.73	128	44	97
May	5.39	2.17	190	70	122
June to May	42.80	23.02			
1892-93.					
June	4.33	2.37	221	76	133
July	3.83	.53	40	15	30
August	4.63	.53	40	12	30
September	2.06	.47	53	8	26
October	.71	.16	10	8	8.8
November	6.80	1.53	224	24	86
December	1.55	1.62	140	53	92
January	4.07	1.86	212	50	104
February	6.72	3.73	293	124	212
March	3.55	6.82	614	331	383
April	4.83	4.26	277	196	240
May	5.66	4.98	606	104	280
June to May	48.74	28.86			

In past years this river has been important as a power stream, about 18 sites, with a total of 1,034 horsepower, having been developed. They have nearly all been acquired by the East Jersey Water Company and the city of Newark, and the whole drainage area will eventually be reserved for water supply. There remain notable power sites, such as those at Butler and Bloomingdale, and other points along the river, where the value of the manufacturing is still large. Such sites, however, will be preserved only so long as they do not interfere with water conservation, and therefore the future of the river as a power stream is uncertain.

As a gathering ground for water supply the value of this area has been demonstrated to the satisfaction of all concerned. The water now supplied to the city of Newark has proved excellent, and has been the means of improving the general health of the city to a remarkable extent. On account of various laxities in preparing the reservoirs and because of other circumstances the water has not been as free from sediment as is considered desirable, but sources of contamination have been largely removed, and analyses show that the character of the water is uniformly satisfactory. At the present time only the upper part of the area is reserved for a gathering ground, the water being stored in three reservoirs. That at Oak Ridge has a capacity of 2,555,000,000 gallons and is 383 acres in extent. Clinton reservoir has an area of 423 acres, a drainage area of 9.5 square miles,

and a capacity of 3,518,000,000 gallons. Canistear reservoir has a capacity of 2,500,000,000 gallons and is 350 acres in extent.

With 7 inches storage upon the entire drainage area, 14 inches may be collected annually, equal to a total daily supply of 56,000,000 gallons. In the report of the Geological Survey of the State (Vol. III, 1894, p. 179) a list of possible reservoir sites in this drainage area includes 10 locations, with a combined capacity of 23,920,000,000 gallons.

ROCKAWAY RIVER.

This stream is 40 miles long from source to mouth and has a drainage area of about 140 square miles, more than 80 per cent of which is in forest. It bears a strong resemblance to the Pequanac, although it is much less uniform in character. Within this area are numerous ponds and lakes, which afford a large proportion of storage. Splitrock Pond is 315 acres in extent, with a watershed of about 5 square miles. With the present 12-foot dam raised 3½ feet it would, according to the measurements of Mr. Vermeule, have a capacity of over 700,000,000 gallons and would, if drawn off 7 inches on the watershed, supply continuously 3,500,000 gallons daily. Green Pond, at an elevation of 1,048 feet and with an area of 460 acres, could be made to supply 1,200,000 gallons daily.

The flow of the river at Dover, as determined by the Geological Survey of New Jersey (Vol. III, 1894, p. 182), is given in Table VIII, the readings for which were made on Sundays, when the mills were shut down.

TABLE VIII.—*Flow of Rockaway River at Dover, 1890.*

[Drainage area, 52.2 square miles.]

Date.	Cubic feet per second.	Inches on watershed in 24 hours.	Date.	Cubic feet per second.	Inches on watershed in 24 hours.
March 30	253	0.180	August 24	78	0.056
April 6	182	.129	August 31	78	.056
April 13	182	.129	September 7	50	.036
April 20	115	.082	September 14	165	.117
April 27	115	.082	September 21	129	.092
May 4	175	.125	September 28	89	.063
May 11	103	.071	September 30	39	.028
May 18	182	.129	October 5	136	.097
May 25	121	.086	October 12	104	.074
June 1	128	.091	October 19	159	.113
June 8	110	.078	October 26	208	.148
June 15	115	.082	November 2	116	.083
June 22	115	.082	November 9	88	.063
June 29	41	.029	November 16	88	.063
July 6	80	.057	November 23	61	.043
July 20	39	.028	December 7	88	.063
July 27	272	.194	December 14	43	.031
August 3	318	.226	December 21	88	.063
August 17	39	.028			

As a source of power the Rockaway has in the past been one of the most valuable rivers in the State, furnishing in the year 1890, at 29 sites, 1,398 horsepower, with many available sites unimproved. The

water rights upon the area have now come into the possession of Jersey City, and the river will be used as a source of water supply, and in the future will not figure largely as a power stream.

Above Old Boonton, on the Rockaway shed, there are 122.5 square miles of highland-drainage area which have been included in the tract set apart for the water supply of Jersey City. The plan proposed by Patrick H. Flynn, contractor, and which was accepted by the city, provides that a main intake and reservoir shall be located at Old Boonton, which shall leave an area, as improved, for 50,000,000 gallons daily delivery, of 949 acres and a capacity above the effluent pipes of 1,362,000,000 gallons. Tributary to this reservoir will be the whole flow of Rockaway River, including the waters of Longwood Valley, Green Pond, Denmark Lake, Beach Glen, Splitrock Pond, Dixon Pond, Showgum Lake, and tributary streams.

Provision will be made for increasing the supply by raising the height of the dam so that the area of the reservoir will be 1,177 acres, with a capacity of 12,683,000,000 gallons, and a supply of 70,000,000 gallons daily.

WHIPPANY RIVER.

This stream is comparatively unimportant as a source of power, and the area is not well developed to become a source of water supply. The population on the watershed is large and furnishes a large measure of pollution, to which reference will be made below.

POLLUTION OF PASSAIC RIVER SYSTEM.

It needs only a superficial inspection of the Passaic River at any point below the city of Paterson to discover the bad state of affairs there existing. Commencing in a small way, the sewerage systems emptying into this part of the stream have increased with the growth of the municipalities, until the conditions all along the lower reaches of the river have become insufferable. The clutch of pollution seems to have fastened itself there, and in spite of the best efforts of intelligent men no satisfactory legislation has yet been enacted to alleviate the conditions. In considering the Lower Passaic—i. e., that part lying between Little Falls and Newark Bay—the Passaic Valley sewerage commission, created by an act of the legislature of New Jersey in February, 1896, described the conditions in its report dated February, 1897, as follows:

The great extent of the pollution of the Lower Passaic may be illustrated in several ways. It is apparent to the eye in the conditions of the river during the summer, in the foulness of the shores where sewage-laden mud, when exposed to the sun, gives out foul odors; and it is demonstrated by every practical test. The cities of Newark and Jersey City have been compelled to seek water supplies elsewhere at great expense, and the immediate decrease in zymotic diseases in those places which followed the change has shown how necessary it was.

Fish life, excepting a few hardy kinds, has disappeared from the river, and fifteen years ago shad, which formerly frequented the stream, abandoned it. The manufacturers have reported that the acid in the sewage-laden water has affected the boilers so as to make its use inadvisable. The use of the river for pleasure purposes, which at one time made it a delight to thousands, has become comparatively infrequent, and the attractiveness of the river [see Pl. I, *A*] may be said to have disappeared.

The commissioners in their meetings at the various towns on the river found all citizens deeply concerned and anxious for action to remove pollution. Their testimony was substantially identical, and while there was a natural desire to avoid doing injury to the fair name of their towns, it was their unanimous sentiment that the pollution of the river had caused great depreciation in property values along the stream. During the hot months residences within a short distance of the river were reported to be almost uninhabitable on account of the stench, and the necessity of keeping windows closed on hot nights to bar out the evil odors was frequently mentioned as showing the extent of the actual nuisance. The injury to property at all points below Paterson was testified to be large and increasing, despite the many natural advantages of the valley and its neighboring heights for suburban residences. The actual direct effect of the stench upon the public health was discussed with caution by physicians and health authorities, but that its influences were gravely injurious admitted of no doubt.

Finally, the quantity of sewage discharged, compared with the low-water flow of the river, was shown to be beyond the power of the river to assimilate, and exceeded the limits which have been regarded as permissible for an open stream by sanitary authorities of other countries and States.

The ratio of increase in population for the Lower Passaic district from 1880 to 1890 is placed by the engineers at 43.2 per cent, and from 1890 to 1895 at 22.6, the ratio for the five years thus exceeding that of the decade previous. The river now receives the sewage of the cities of Paterson, Passaic, Orange, Newark, and the towns of East Orange, Bloomfield, Montclair, Harrison, Kearney, East Newark, and part of Rutherford. Sewerage facilities for other places are an admitted necessity of the early future. It therefore appears beyond question that the river pollution is sure to increase enormously unless remedial measures be taken.

This part of the investigation by the commissioners therefore demonstrated:

That the daily discharge of 70,000,000 gallons of sewage into the Passaic River below the Great Falls of Paterson is beyond its power to assimilate.

That the pollution has become a nuisance to residents along the banks by the stench and had caused depreciation of property and injury to health.

That the fisheries had been destroyed.

That the river had ceased to be desirable for pleasure purposes, boating, bathing, etc., no longer possessing the park values which so generous a stream should afford the large population on its banks.

That the use of the river for manufacturing purposes is suffering on account of the pollution.

In short, the pollution of the Lower Passaic River appeared to the commissioners to be completely established as a public nuisance, an injury to health, and an increasing menace to property interests from the beginning at the Great Falls to below Newark.

The report of the commission, quoted above, in dealing with conditions of the Upper Passaic portion, states that the pollution upon that part of the drainage area was inconsiderable, yet the rapid growth of the municipalities thereon warranted the belief that in a short

space of time the pollution entering the river above Little Falls would be as unfavorable in its effect upon the river as that of the Lower Passaic, and recommended that there be absolute prohibition of the use of the main stream or tributaries of the Upper Passaic watershed for any crude sewage, and that the extent to which filtered effluent may be permitted to enter this stream should be subject to regulation by a commission in charge of the purification of the river, with power to prevent nuisance. The increase in population since that time has been beyond the expectations of the commission, and the laws that have since been enacted for the protection of rivers are provided with unsatisfactory means of enforcement. There is no doubt whatever that the pollution within this area is far more extensive than at the date of the above-quoted report. It is also true that the commission recognized the enormous burden imposed by the pollution in the Lower Passaic and gave more careful attention to that part of the river than they did to the highland area. Let us therefore examine the conditions as they now exist in the river system above Great Falls, Paterson.

Four miles up the river is Little Falls, a town of 2,908 inhabitants, without any public system of sewerage, but nevertheless producing considerable pollution from private drains and factories. Analyses that have been made of the water at Little Falls dam and at Great Falls dam show an appreciable increase in organic matter at the lower station, and bacteriological examinations indicate at times even more strongly the presence of sewage below Little Falls. The cities of Paterson and Passaic, which have in the past taken their water supply from the head of Great Falls, have not during that time been free from epidemics of typhoid, which, in the opinion of the sanitary officials, have been traceable to the water supply.

Farther up the river, beyond the Great Meadows, are the towns of Madison and Chatham, containing, respectively, 3,754 and 1,361 inhabitants. Neither of these has a sewerage system, although one is projected in Madison. The pollution of the river at these towns is more than would be expected from places of their size and condition. Still farther up is Summit, a city of 5,302 inhabitants, having a sewerage system that has been extended through the more thickly settled parts of the city. A sand-filtration area has been provided on the banks of the Passaic, which has been unsuccessful from the standpoint of purification, the effluent being not at all satisfactory, putrifying in a short time and causing a serious nuisance at the Chatham dam, a few miles below. Indeed, so unsatisfactory has been the work of this filter that its abandonment has been practically decided upon. A plan has received legislative authority whereby Summit may join with Milburn, Vailsburg, West Orange, South Orange, and a part of Newark in the construction of a tide-water trunk sewer which shall discharge into Arthur Kill.

Upon the Whippany are Morristown and Morris Plains, the former

with a population of 11,267, both without sewerage systems, and the former especially contributing a large amount of sewage by means of private drains from houses and factories, so that the river and its branches ramifying through the city often present a most disgusting sight. It is not apparent to the observer that the municipal authorities there have taken any effectual steps to prevent pollution of these streams, and in certain parts of the town sewage may be seen running into the brooks via the street gutters.

Boonton, Rockaway, and Dover, with a combined population of 11,322, are situated upon Rockaway River. All three are in the drainage area embraced in the reservoir now under construction, the waters of which will reach up well into the town of Boonton. In the contract entered into between the city of Jersey City and Patrick H. Flynn, the contractor, there is a provision that all sewage shall be diverted from the catchment area, and a plan has been provided whereby the contractor shall build an intercepting sewer which shall collect all the sewage from these three municipalities and empty it into the Rockaway below Old Boonton. The present plan, therefore, will not relieve the river of its pollution, except upon that part of the Rockaway above the proposed dam.

Upon the streams converging into the Pompton are Bloomingdale and Butler, with upward of 800 people, and Pompton Village, at the mouth of the Wanaque, and upon the Ramapo in New York State are Suffern, Hillburn, and Tuxedo, the former of which has a small sewerage system emptying into the river. Here is an instance of interstate pollution. Although at present not of great importance, there is every reason to believe that as the town increases in size the pollution may become sufficiently extensive to affect the value of the Ramapo watershed in New Jersey. The laws that may be enacted and the surveillance which it is hoped to establish in New Jersey over watersheds can have little effect in New York, be they enforced ever so efficiently. The same is true of the upper part of the Wanaque watershed, and also of Saddle River. Greenwood Lake, situated in both States, is a favorite summer resort, within easy distance of New York. There is likely to develop a community of no mean importance at the New York head in years to come, the pollution from which would injure not only the water-supply value of the lake, but also the ice industry, which amounts annually to about 60,000 tons.

In the year 1899 the East Jersey Water Company, being compelled to give up the water from the Pequanac, which would in September, 1900, pass into the hands of the city of Newark, offered to another municipality with which the company was under contract, and to which it was then furnishing Pequanac water, a supply from the new intake at Little Falls. The town officials not being satisfied with the proposed change, and believing the water to be inferior to that of the highland stream, employed Mr. George W. Fuller, of New York,

to examine into and report upon the subject. After a period lasting six months, during which the whole matter was explored in minute detail, Mr. Fuller submitted his report, from which the following extract is made:

While admitting that Passaic River water from Little Falls might be used * * * without any serious detriment to the public health, it is my judgment that this water can not, from a strictly sanitary standpoint, be rated as a pure and wholesome water. This judgment is based on the fact that there are no thoroughly efficient means of eliminating the germs of water-borne diseases before they shall reach the consumers at * * * in the event that such disease should become prevalent at one of nearly a dozen centers of population.

The Passaic Valley sewerage commission was succeded in 1889 by the State sewerage commission. The report of this body to the legislative session of 1900 reads concerning the Passaic River as follows:

The purification of the Passaic River has been and is the greatest problem which has demanded the attention of the commission. The magnitude of the undertaking can hardly be exaggerated. The report of the Passaic Valley sewerage commission of 1897 set forth the then existing conditions. The commissioners appointed under the act of 1898 to "consider the pollution of rivers and streams in this State" said, referring to the Passaic River: "The condition of the Passaic River has been getting worse, and during the last summer the conditions were even more intolerable than during the drought of 1895." Bad as was the condition then, that during the summer of 1899 has been far worse than ever before known. As early as June serious complaints were made of its condition, which have continued during the whole summer and into the autumn.

It is a common error to suppose that the condition is solely the result of pollution of Paterson and Passaic and the municipalities at or above the head of tide water. While these communities are large polluters of the river, others are equally guilty. During much of the time the Passaic River is little more than a tidal estuary, in which the outward flow of the tide is not of sufficient duration to empty the river of the polluted water. The incoming tide meets the sewage of Newark, Orange, Bloomfield, Montclair, Harrison, and neighboring towns, driving it up the river to meet that coming from above, so that to a great extent the same water, with constantly increasing quantities of sewage being added, is driven up and drawn down by the tide until large rainfalls occur, when there may be a flow of water from above sufficient to force the sewage out and fill the river with clean water. This temporary relief continues as long as there is water coming down sufficient to force back the tide and allow the sewage to find its way into the bay.

The commission received numerous complaints from residents along the river, it having been necessary for people a half a mile from the river to close their windows during the hottest weather to keep out the stench. The constantly increasing quantity of sewage being poured into the river, together with the decreasing amount of water coming down for the dilution of the sewage, have hastened the time when some remedial action has become imperative. It is recommended that legislative action be promptly taken to abate the foul condition of the Passaic River. To this end a bill has been drafted empowering the State sewerage commission to require such other disposition of the sewage and other polluting substance as shall meet its approval, believing that when it becomes obligatory for those fouling the river to do something else with their sewage they will join with your commission in seeking the best way. The commission has sought to unite

the different municipalities in some voluntary action, and with that end in view invited the several municipalities now discharging sewage into the river to appoint committees to meet with the State commission for the purpose of considering the subject.

In a further report to the legislature of 1901, the same commission speaks concerning the Passaic as follows:

The sewage pollution of the Passaic has, during the last year, increased in its evil effects. Heretofore the objectionable odors have been limited to the summer months; but during the last autumn the stench continued until the freezing weather locked the foulness into ice. The rainfall was below the average during the autumn, and wide spaces of sewage-befouled mud were exposed to the air, giving forth nauseating odors. The effects were felt with severity all the way from Paterson to Newark Bay, and factory hands in Paterson and in Newark, near the river, were compelled to stop work a number of times on account of nausea from the river stench. .* * *

The flow of fresh water from above Great Falls is showing a steady diminution, principally owing to the diversion of the river water above for city supplies, and the amount of the discharge will unquestionably increase constantly. The effect upon the river above the tidal flow, between Paterson and Dundee dam, is disastrous, leaving insufficient water to carry down ordinary sewage discharge, much of which lodged during the summer and autumn in the bare river bed, giving forth stench and threatening disease in the heart of Paterson. The scouring by floods, which served for a periodical cleansing, is now rarely effective, and the conditions seem to grow worse. The evil condition of the whole river can scarcely be exaggerated, and what was apparent to the instructed four years ago is now evident to any person who may casually observe the river.

VALUE OF PASSAIC RIVER SYSTEM AND ITS MODIFICATION BY POLLUTION.

WATER POWER AND WATER SUPPLY.

As a source of power the Passaic system is worth about $1,500,000. According to the report of Mr. Vermeule the total available gross horsepower of the stream is 8,924. Assuming the usual efficiency of 70 per cent upon the wheel, there may be developed a net horsepower of 6,246.8, which, at the average New Jersey rental of $22.50 per horsepower, would yield an annual rental of $140,553. With a capitalization of 10 per cent we find a total valuation of $1,405,530.

The value of the river as a source of water supply is a more difficult problem to estimate and varies according to the means used to collect the water. It has already been stated that at the head of Little Falls the river will supply without storage about 85,000,000 gallons daily. The only important addition to the flow below this point is Saddle River, which furnishes daily a minimum of about 2,600,000 more throughout all seasons. This total of about 87,600,000 gallons is undoubtedly a conservative estimate of the supply available at the Belleville pumping station, and the total flow of the river past that point would, except in extraordinary cases, be far greater. If, then, pollution were excluded from the Passaic and the minimum flow were

pumped from the river at Belleville, there would be no disturbance of the power value of the river, so that, in addition to the power valuation, there would be the value of the water. Pumped from the river at Belleville and raised to a height sufficient to serve the metropolitan areas of Essex and Hudson counties, this water, at a fair valuation, would bring $25 per million gallons, assuming, of course, that the present pollution had never existed.

If, however, storage is provided in the highland areas and the water is allowed to flow into the cities by gravity we shall have a measure of resource far greater than that above estimated. Mr. Vermeule states that 666,094 gallons per square mile are daily collectible with storage upon the Passaic system. Considering only the 773 square miles above Little Falls, and the 60.7 square miles of Saddle River there can be developed through storage a resource equal to 555,000,000 gallons daily. This amount of water, utilized at the extremely low rate of $15 per million gallons and on the basis of only 60 per cent conservance, would yield an annual income of $1,823,175, which capitalized at 10 per cent equals $18,231,750. Under such a system the water power would be largely if not completely destroyed, so that this value would necessarily be deducted from the above figures.

It has already been shown that the water pumped from the river below Belleville is polluted beyond all possibility of use in its crude state, and indeed the city of Newark had this fact brought to its attention during the winter of 1899, when, during a continued cold season, the consumption of water reached the limit prescribed in the contract and the water was again pumped into the mains at Belleville. The typhoid epidemic resulting therefrom was a severe lesson.

Expert examination has shown that it is unsafe to use the water from Little Falls in its crude state. If we examine the history of the water supply upon the Passaic we shall find the following facts: Previous to the year 1888 the municipalities of Newark, Harrison, Arlington, Belleville, Nutley, Kearney, Passaic, and Paterson, situated upon the Lower Passaic, and Jersey City, situated upon the Hudson, all derived their water supply from the Passaic. On the one side of the river Jersey City, Harrison, and Kearney received their supply from the intake owned by the first-mentioned city, while across the river, at Belleville, was situated the Newark pumping station. From the latter intake there were pumped 16 to 20 million gallons daily, at a cost of $15 to $17 per million gallons, while at the former intake about the same amount was taken, at approximately the same cost. Passaic and Paterson were supplied from an intake situated at the head of Great Falls and owned by the Passaic Water Company. All of these municipalities, especially those supplied from the Newark and Jersey City intakes, suffered excessively from typhoid fever, due to sewage pollution in the river.

In 1889 the source of supply of the Newark system was transferred to the Pequanac area under a contract with the East Jersey Water Company, and in September, 1900, the ownership passed to the city at the cost of $6,000,000. Although the change from Belleville to Pequanac involved a change from a pumping to a gravity system, which in years to come will be more economical, during a long term of years the fixed charges upon the plant will make the water cost Newark $30 per million gallons, an amount equal to twice the cost of the Belleville water.

The source of supply for Jersey City was, in the year 1898, transferred to the new intake of the East Jersey Water Company at Little Falls, a temporary arrangement which will continue during the completion of the dam at Old Boonton, on the Rockaway, which, when developed to a capacity of 70,000,000 gallons daily, will cost the city about $9,000,000. Here, again, the transference from pumping to gravity will, in the end, be the means of securing the water at a cheaper rate, but the fixed charges in the meantime will operate similarly to those in Newark.

In 1899 the source of supply of Paterson, Passaic, and Nutley, which had for years been taken at the head of Great Falls, was transferred to the new intake at Little Falls. The reasons for this change are not entirely confined to those of pollution, although there is no doubt, and indeed it is admitted by the officials of that company, that pollution from the town of Little Falls had rendered the water unsafe for domestic use. The cost of this change is, of course, not made public, yet it can be easily understood that so radical a move must have been attended by a considerable outlay, as well as the surrendering of large values by the disuse of the Great Falls pumping plant.

The opinion of Mr. Fuller, already stated, having been unfavorable to the Little Falls water in its raw state, and pressure having been brought to bear upon the company by the municipalities using it, it became necessary to construct a filter, which is nearing completion and which will cost about $400,000. Subsequent additional charges for maintenance will amount to about $6 per million gallons.

ICE INDUSTRY.

Up to the present time the value of the Passaic system as a source of ice supply has not been greatly injured by pollution. Greenwood Lake, which is by far the most valuable of the Passaic ice fields, affords an annual average supply of about 60,000 tons. On the river below Paterson there was in former times a fairly large ice industry, amounting in favorable seasons to 10,000 tons. It has, however, been completely destroyed by the pollution of the river, and the first of a proposed series of suits against the city of Paterson has been won in the lower court by an injured ice dealer.

FISH.

There was a time when Passaic shad were as highly valued in the eastern markets as are those in the North River to-day. The industry flourished and was a source of no inconsiderable income to the dwellers along the river. Under the present conditions only one hardy, inedible fish will live in these waters.

REALTY VALUES.

Pollution of the Passaic has caused its greatest damage in the reduction of realty values. We can not estimate with any degree of correctness the amount of this damage, but we know that it is enormous. The banks of the Passaic from Paterson to Newark are naturally attractive, and there is, in the northern portion of New Jersey, no more suitable nucleus for a public park. Especially along the shores of Dundee Lake are there situations which are ideal for suburban homes, and their accessibility to the large cities of the metropolitan area would naturally make them desirable in the eyes of that constantly increasing number of city business men who are making for themselves homes outside of Greater New York. Yet the area is practically uninhabitable—the residents along the shores are principally those who have lived there from birth and inherited the property upon which they dwell, or who moved there before the present conditions existed, and are encumbered with property which they can neither abandon nor sell. Only a few years ago the value of this land for farming purposes was from $500 to $800 per acre, and building sites were held at a much higher value. For one piece of property of 14 acres, in a particularly favored situation, $40,000 was refused less than twenty years ago. To-day, however, this plot can not be sold at any price, nor is there any market for the property along the entire shore of the lake.

SUMMARY.

We have seen that the natural resources of the Passaic system are very extensive, embracing water power, water supply, ice fields, fisheries, transportation, and natural scenic advantages, but that all but one of these have been so damaged by pollution as to produce the following results:

1. Abandonment of three water-supply intakes and the establishment of three others, at a total expense of not less than $20,000,000.
2. Extensive decline of power values because of inadaptability of water for use in boilers and in manufacturing processes.
3. Loss of annual harvest of ice weighing 10,000 tons.
4. Absolute destruction of fisheries in lower valley.
5. Impairment of realty values, the extent of which can not be too highly estimated in view of the fact that similar properties in clean localities have been made of immense value.

HUDSON RIVER.

Perhaps the most resourceful and certainly the most famous river on the Atlantic coastal plain is the Hudson. The history of its discovery and development has been many times retold; its physical characteristics are subjects of study in common schools, and its resources, especially from the standpoint of water power, have been repeatedly described, notably by Prof. Dwight Porter, in Volume XVI of the Tenth Census report, and later by Mr. George W. Rafter, C. E., in Nos. 24 and 25 of the series to which this paper belongs. It therefore seems unnecessary to consider this branch of the subject in the following pages, and as, up to the present time, very little, if any, detriment has arisen to water-power values through sewage pollution anywhere in the basin, the subject of power is not pertinent.

The extreme flatness of the bed of the Hudson throughout the first 150 miles from its mouth, and the depth of water maintained thereon, give to it the character of an elongated bay, or arm of the ocean, rather than that of a river. At Troy, the head of natural navigation and also of tide water, the level of the river at mean low tide is only 2.07 feet above mean sea level in New York harbor. Under these conditions, the influence of salt water extends a great distance inland, the brackish taste being appreciable at times at Poughkeepsie, 80 miles above Sandy Hook (see Pl. V, *A*). The influx of sea water by the flood tide was studied by Mr. H. L. Mandarin, under the authority of the United States Coast and Geodetic Survey, in 1871, the results of which may be seen in Table IX.

TABLE IX.—*Specific gravities of water in the Hudson River at and below the surface, reduced to a temperature of 60° F., September, 1871.*

Distance from Sandy Hook.	Station.	End of flow current.			End of ebb current.		
		Surface, specific gravity.	Below.		Surface, specific gravity.	Below.	
			Depth.	Specific gravity.		Depth.	Specific gravity.
Nautical miles.			*Feet.*			*Feet.*	
17½	Twentieth street	1.0198	57	1.0206	[a] 1.0141	53	1.0181
34½	Dobbs Ferry	1.0024	30	1.0114	1.0013	30	1.0022
38½	Tarrytown	1.0021	30	1.0069	1.0016	30	1.0076
42½	Tellers Point	1.0011	30	1.0087	1.0013	30	1.0087
49½	Verplanks Point	1.0012	30	1.0084	1.0014	30	1.0014
53½	Iona Island	1.0017	30	1.0087	1.0012	30	1.0012
56½	Dermings Landing	1.0016	.....	1.0028	1.0012	.....	1.0021
61	Cold Spring	1.0015	30	1.0026	1.0010	.....	.....
65	New Windsor	.....	.....	.....	1.0006	.....	.....
70½	Carthage	1.0006	48	1.0016	1.0006	48	1.0012
75	Barnegat	1.0006	60	1.0006	1.0006	60	1.0006
79½	Poughkeepsie	1.0007	48	1.0007	1.0006	48	1.0005

[a] 1872.

The drainage area of the Hudson is estimated by Professor Porter as 13,366 square miles, 8,034 of this being above Troy. Its tributaries extend into New Jersey, Massachusetts, and Vermont, and the minimum flow past Poughkeepsie is said to be about 1,500,000,000 gallons daily. In his report to the Merchants' Association of New York upon

A. POUGHKEEPSIE, N. Y., THE HEAD OF SALT-WATER INFLUENCE ON THE HUDSON.

From photograph in possession of American Museum of Natural History, New York City

B. DELAWARE AND HUDSON CANAL TERMINUS, RONDOUT, N. Y.

From photograph in possession of American Museum of Natural History, New York City

available sources of water supply for that city Mr. James H. Fuertes computed a probable flow of 2,900,000,000 gallons daily at the time of the measurements in the table above.

Before considering the subject of pollution in the Hudson it will be advisable to examine briefly into the character of the river and to contrast the conditions which prevail with those dealt with in connection with the Passaic. We have seen that the Passaic River is a comparatively small stream, and that it has upon its banks numerous large cities and towns which pour into it a volume of sewage at times greater than the flow of the river. In the Hudson Basin we have an area more than thirteen times the size of the Passaic, contributing to a flow which exceeds the latter in like proportion. Consequently the amount of sewage poured into the river must be as great in proportion to the flow as that in the Passaic and of similar character and distribution in order to accomplish the serious results that we have noted in the latter. From the cities in the basin of the Hudson River and its tributaries there comes a pollution far greater in amount than from those in the Passaic Basin, yet the proportion of contaminating matter to the total flow is so much less in the Hudson than in the Passaic that they bear no significant relation to one another. Few if any points in the Hudson watershed have been damaged to a degree which at all compares with the distress that has arisen along the Passaic Valley, because of the fact that the natural flow of the Hudson so largely dilutes the sewage poured into it that not infrequently the effects thereof are not traceable by sanitary analysis. In the year 1893 Dr. Thomas M. Drown, now president of Lehigh University, found that the water from the river above Poughkeepsie, which is below practically all of the polluting points in the basin, did not reveal upon analysis any serious traces of sewage matter; indeed, the water appeared altogether better than that of the Schuylkill River, from which the city of Philadelphia has for years been drawing the greater part of its supply.

TABLE X.—*Average analyses of Hudson River water at Poughkeepsie, June, 1893.*[a]

[Parts per 100,000.]

	Albumenoid ammonia.	Free ammonia.	Nitrogen as nitrates.	Nitrogen as nitrites.	Oxygen consumed.	Chlorine.
At intake of Poughkeepsie waterworks, average of 9 samples taken, 5-8 feet below surface	0.0144	0.0061	0.0007	0.0108	0.5197	0.110
At one-third distance from east shore, average of 19 samples taken at surface, 30 feet and 50 feet below surface	.0137	.0064	.0006	.0106	.5159	.107
At two-thirds distance from the east shore, average of 19 samples taken at surface, 30 feet and 50 feet below surface	.0149	.0064	.0006	.0110	.5389	.109
7 miles above Poughkeepsie, average of 6 samples across river, 30 feet below surface	.0143	.0064	.0006	.0095	.4606	.113

[a] From report of James H. Fuertes to Merchants' Association of New York.

In considering pollution upon the Hudson it will be necessary to take into account only that part lying above Poughkeepsie, for salt-water influence extends up to this point, and this of itself destroys many resources which have been noted in the preceding pages as subject to damage by pollution. All succeeding calculations will be based upon the watershed above this point unless otherwise noted. Above Poughkeepsie the river still maintains the character of an inland-traffic course, plied by steamers and canal boats. Pollution is therefore unavoidable, for if all city sewage were excluded from the river the ejecta from passenger steamers passing up and down would make the raw water unsafe as a domestic supply, especially when such matter was discharged near a supply intake. It appears, then, from what has gone before, that from the standpoint of pollution the Hudson divides into three sections: First, that within the salt-water influence, i. e., from New York to Poughkeepsie; second, that between Poughkeepsie and Troy, which by reason of its commercial value must be polluted; third, the upper or highland section, along which power sites are available and which partakes of the character of an ordinary power stream. In order to show the extent and population of the country drained by the Hudson the following table has been prepared, in which the populations have been calculated according to the Twelfth Census Reports:

TABLE XI.—*Drainage areas and population in the Hudson River Basin.*

State.	County.	Number of municipalities.	Combined area in square miles.	Population.	Population per square mile.	Sewered population.
New York	Essex	7	649	11,382	17.5	
	Warren	11	940	29,943	31.8	12,613
	Washington	11	557	31,110	55.9	3,521
	Saratoga	20	800	61,069	76.4	24,173
	Hamilton	8	1,767	4,947	2.8	
	Herkimer	21	1,459	51,049	35	21,074
	Oneida	21	[a] 896.7	117,518	131	71,726
	Lewis	1	[a] 72	917	12.7	
	Madison	1	[a] 39.3	2,024	51.5	
	Otsego	1	[a] 40	1,802	45	
	Fulton	12	567	42,842	75.4	28,479
	Montgomery	11	396	47,488	119.9	20,929
	Schoharie	16	647	26,854	41.5	2,327
	Schenectady	6	200	46,852	234.3	31,682
	Albany	13	499	165,571	331.9	132,382
	Rensselaer	17	643	121,697	189.3	86,383
	Columbia	19	691	43,211	62.5	9,528
	Dutchess	19	772	77,337	100.2	24,029
	Greene	14	660	31,478	47.7	8,219
	Ulster	21	1,157	88,422	76.4	24,535
	Orange	19	683	59,410	86.9	19,495
	Sullivan	3	[a] 60.7	8,121	13.4	
	Delaware	1	[a] 45	2,134	47.4	
Massachusetts	Berkshire	8	[a] 239	43,191	180.7	
Vermont	Bennington	13	[a] 520	19,407	37.3	
New Jersey	Sussex	10	[a] 292	13,031	44.6	

[a] These areas are estimated and are only approximately correct.

North of Poughkeepsie, on the east side, there flow into the Hudson, in the order mentioned, Crum Elbow Creek, Fallsburg and Landsman kills, Stony Creek, Roeliff Jansen Kill, Claverack and Kinderhook

creeks, Moordener, Wynant and Poeston kills, Hoosic River, Batten Kill, Moses Kill, and Schroon River. Of these, Crum Elbow Creek, Fallsburg Kill, Stony and Claverack creeks, Roeliff Jansen and Moses kills, and Schroon River are not important from the standpoint of pollution, as they flow into the Hudson in a comparatively pure state. Landsman and Wynant kills and Kinderhook Creek receive a certain amount of pollution indirectly at the centers of population in the courses of the three streams. Hoosic River is badly polluted, and Batten Kill to a less extent.

On the west side of the Hudson the river branches enter in the following order: Rondout Creek, Esopus, Catskill, Hannacrois, and Coeyman creeks, Norman Kill, Mohawk River, Anthony Kill, Fish Creek, Snook Kill, and Sacandaga, Indian, Cedar, and Rock rivers. Of these, Hannacrois and Coeyman creeks, Norman and Snook kills, and Sacandaga, Indian, Cedar, and Rock rivers need no discussion because of their comparative freedom from pollution. Rondout, Kaaterskill, and Catskill creeks receive considerable indirect and private drain pollution, while Wallkill and Mohawk rivers and Esopus and Fish creeks are directly polluted by sewage systems.

It has already been stated that pollution along the middle or navigable section of the Hudson above salt-water influence is unavoidable, even if city sewage were entirely excluded from the river. In order to make the whole pure it would be necessary to close the river to commerce, and as its value as a means of transportation far overtops all other values which it may have, such a suggestion is manifestly absurd. We are forced, then, to conclude that, for the present at least, while pollution may unfit the Hudson up to Troy for use as a domestic water supply without filtration, the damage to the resources is insignifiant compared to the damage which would occur by excluding sewage from the river. While the water remains fit for filtration, then, the Middle Hudson is of more value as a polluted stream than it would be if preserved unpolluted. But if the time should ever come when the condition of the Hudson should approach that of the Lower Passaic, then it would be highly necessary to enforce sewage purification upon the towns and cities along the banks. Such a contingency is, however, very remote.

The reports of the Tenth, Eleventh, and Twelfth Census bureaus show that the growth in population along the Hudson below the mouth of the Mohawk has not been marked. During the last decade the cities of Albany, Troy, and Hudson have actually decreased in population, while the gain in others has been subnormal. Any alarming increase in the amount of sewage poured into the Hudson can not, therefore, be expected, and it will not probably be in danger of becoming the consummate pest that the Passaic has become should there be no regulation of sewage disposal for generations.

It will be necessary to consider the sources of pollution along the

middle section of the Hudson in order that the conditions there existing may be clearly shown. Catskill, Hudson, Albany, Rensselaer, Watervliet, and Troy (including Lansingburg) are sewered cities along the middle section of the river, containing a combined population of 204,196. The amount of sewage discharged from these places is unknown; no gagings have been made, and any estimate which might be given would not be even approximately correct. Judging from the population involved it might be expressed as about one-half that discharged into the lower section of the Passaic.

Catskill is a village of 5,484 inhabitants, having shown a growth of 11.5 per cent during the last decade. The manufacture of bricks forms a large industry, and the textile mills are important. Its source of water supply is the Hudson, the water from which is filtered previous to distribution. A system of sewerage has been extended throughout the corporate limits, and the sewage is discharged, unpurified, into the mouth of Catskill Creek.

Hudson is a city in Columbia County, which is largely devoted to manufactures of iron and lumber. It is also the seat of several State homes and schools. During the past decade the population has dropped from 9,970 to 9,528. It is supplied with filtered water from the Hudson, and discharges about 1,200,000 gallons of unpurified sewage daily through a combined system of sewerage.

Albany, the capital of the State of New York, has also decreased in population. During the decade 1890–1900 the loss amounted to .81 per cent. Although in the past the city has suffered severely from polluted water supply, the filters recently installed under the direction of Mr. Allen Hazen, M. Am. Soc. C. E., have made Hudson River water acceptable. The sewers discharge raw wastes into the Hudson, but there appear to be no available records of gagings of the amount. The average daily consumption of water at the present time is, however, about 18,000,000 gallons.

Rensselaer, situated opposite Albany, in Rensselaer County, is a municipality in which there has been a slight growth, the population, according to the Twelfth Census, being 7,466. It is supplied with water from the Hudson, filtered by a Jewell mechanical filter. A separate system of sewerage discharges raw wastes into the river, the amount of which is said to average about 1,500,000 gallons daily. The accuracy of this statement is uncertain, however, and it is probable that the actual discharge is considerably more than the above.

Watervliet, formerly known as West Troy, and Troy, which now includes the former city of Lansingburg, have a combined population of 87,567. The increase in population at Watervliet and Lansingburg has been normal, but at Troy the Twelfth Census returns show a decrease in the last decade of 300. Troy water is largely taken from the Hudson and has caused a great amount of disease. Plans are now being executed which will relieve this condition by the conservance of a highland supply a short distance away from the city.

At Lansingburg the drainage into the Hudson has been defective, and plans for making more perfect, more direct pollution have been approved by the State board of health.

Besides the above-mentioned municipalities there are located upon the banks of this section of the Hudson the following small places included in Table XII, some of which have no public sewerage systems, yet which furnish considerable pollution.

TABLE XII.—*Population, water supply, and sewerage of certain towns on Hudson River.*

Place.	Population.			Water supply.	Sewerage.
	1890.	1900.	Change.		
Saugerties	4,227	3,679	− 540	Yes	No.
Athens	2,024	2,171	+ 147	No	Do.
New Baltimore	2,455	2,283	− 172	Yes	Do.
Coeymans	3,669	3,925	+ 283	do	Do.
Hyde Park	2,821	2,806	− 15	No	Do.
Bath	3,261	4,994	+1,733	Yes	Do.
Rhinebeck	1,649	1,494	− 155	do	Do.
Tivoli	1,350	1,153	− 197		
Castleton	1,127	1,214	+ 87		
Coxsackie	1,611	2,735	+1,124	Yes	Yes.

Above Troy navigation on the Hudson is confined to the transfer of canal boats through the pool of the State dam at Troy up the river to Waterford, where they enter the Champlain Canal. According to recent reports there has been a reduction in canal traffic in New York State, so that the value of the river above Troy for heavy traffic can be regarded as somewhat transitory. Above this point, then, the river is valuable principally for power, water supply, and ice.

Civic pollution becomes more important above the confluence of the Mohawk, where the flow is considerably less, and the danger is that, as the cities increase in population, there will arise conditions similar to those on the Passaic. The cities and villages above Troy have all shown a healthy growth during the past decade, and, strangely enough, have collectively increased at a rate far higher than places nearer the metropolis.

TABLE XIII.—*Centers of pollution on Upper Hudson.*

City.	Population.		Sewerage.	Place of disposal.	Water supply.
	1890.	1900.			
Cohoes	22,519	23,910	Yes	Hudson and Mohawk.	Yes.
Waterford	(a)	3,146		Mohawk and Hudson.	Hudson River.
Mechanicville	2,679	4,695	Combined	Hudson	Plum Brook.
Schuylerville	1,387	1,601	No		No.
Fort Edward	(a)	3,251	Yes	Hudson	Yes.
Sandy Hill	2,895	4,473	No		Do.
Glens Falls	9,509	12,613	Yes	Hudson	Do.

[a] Incorporated since 1890.

The above-named cities and villages represent a sewered population of 47,615. Mechanicville is a village devoted to manufacturing, the thread industry being the most important. It shows a growth of about 74 per cent during the past decade. Schuylerville has considerable private drain pollution, yet it is without marked effect upon the river. At Fort Edward there is a satisfactory water supply, and a sewerage system has been recently constructed which extends nearly throughout the corporate limits.

Sandy Hill is another thriving village, showing a growth of 55 per cent during the last decade. Although no sewerage system has yet been constructed, the river pollution is comparatively serious. In 1896 plans for a system of sewerage and disposal works were submitted to the State board of health and accepted, so that even though nothing further has been accomplished the establishment of another source of pollution can not be far removed. Glens Falls, a short distance above Fort Edward, is supplied with water and sewerage systems, which are well extended through the village. The place of the final disposal of the sewage is described by the village engineer, George P. Slack, as a "sink hole in ledge," which probably means that it takes the most obvious course, i. e., the Hudson River, accompanied, very likely, by a slight purification. This village has a population of 12,613, having increased from 9,509 during the last decade.

This part of the river, comprising in its drainage area about 5,000 square miles, is said to have an average flow of about 174,528,000 cubic feet daily, which is probably approximately correct. It partakes of the nature of a highland river, having a fall from Glens Falls to Troy, a distance of 46.5 miles, of 282 feet, and is largely given up to lumber business and lime manufacture.

Waterford and Cohoes are at the mouth of the Mohawk. At both places mill manufacturing is the largest industry, Cohoes possessing one of the largest cotton mills in the world. Pollution from these two cities, added to that already imparted to the Mohawk from cities above, is responsible for the high morbidity rate from waterborne diseases in the cities of Troy and Albany.

EASTERN TRIBUTARIES OF THE HUDSON.

The tributaries of the Hudson that receive only pollution incident to the drainage of unoccupied land require only slight consideration in these pages, while those that are comparatively normal as to condition of water do not come within the scope of this discussion. The tributaries entering the Hudson from the east belonging to the first class above noted are Landsman and Wynant kills and Kinderhook Creek.

Landsman Kill, a small stream entering the Hudson at Vanderburg Cove, carries considerable pollution from the village of Rhinebeck, which contains 1,484 inhabitants. A report from the secretary of the

local board of health stated that a water supply has been provided and that the village has no system of sewerage. It is further stated that at least 75,000 gallons of sewage a day enters the stream. The method of estimating this amount is not shown, however, and it is more than probable that the result is a wide approximation made with questionable data. However this may be, it is certain that the amount ejected has no appreciable effect upon the lower reaches of the river, and its presence is apparent locally only in the area immediately around the various points of discharge. The village of Rhinebeck has decreased considerably in population during the past decade, and the question of future pollution at this point can not be regarded as serious.

Wynant Kill empties into the Hudson a short distance below Troy, having flowed northwest through an agricultural region. Its ultimate source of supply is a chain of lakes in and around the town of Sandlake, in Rensselaer County. At Averill Park and other small settlements there is unimportant pollution. The drainage area seems to be slowly losing its population and the future is therefore not regarded with apprehension.

Kinderhook Creek passes through country similar to that drained by Wynant Kill. Upon its banks are the comparatively important settlements of Nassau, Valatie, and Stockport. The latter is upon Claverack Creek near its confluence with Kinderhook. The observations above made may well apply to the conditions upon this creek.

Hoosic River and Batten Kill are polluted to a greater extent than the rivers considered immediately above. Both of these streams, and especially the former, are damaged considerably by contaminating waters.

Upon Hoosic River are the centers of population shown in Table XIV.

TABLE XIV.—*Centers of population on Hoosic River.*

Name.	Population.		Water.	Sewerage.
	1890.	1900.		
Schaghticoke	1,258	1,061	No	No; many private drains in Hoosic.
Johnsonville[a]			do	No.
Valley Falls[a]			do	Do.
Hoosic Falls	7,014	5,671	Yes	Yes; separate system.
Cambridge	1,598	1,578	do	No; many private drains in Owl Kill.
Bennington	3,971	5,656	do	Yes.
North Adams	16,047	24,200	do	Yes; partly emptying into Hoosic.

[a] Part of Pittston town; no separate returns.

The Hoosic drainage basin extends through Rensselaer and parts of Washington and Columbia counties into the States of Vermont and Massachusetts, comprising an area of 730 square miles. The average flow of the river is stated to be about 450 cubic feet per second, with a minimum of 180. It is a most important power system, and for that reason there is a fairly large population within the basin.

At Schaghticoke, a village of 1,061 inhabitants, there is no public water supply and no sewerage system, but there is nevertheless a large amount of pollution from drains and factories, which undoubtedly has an appreciable effect upon the water of the river.

At Hoosic Falls there are 5,671 inhabitants supplied with water from wells dug along the banks of the river. Filtration is such that the pollution above this point does not affect the water drawn from the wells. There is also a separate sewerage system, emptying raw sewage into the Hoosic.

On a branch of the Hoosic called Owl Kill is the village of Cambridge, with 1,578 inhabitants. It has a water supply and no sewers, so that the pollution, although considerable in amount, is somewhat indirect.

Bennington, in Vermont, with a population of 5,656, has a sewerage system emptying into the Wallomsic, a branch of the Hoosic.

At North Adams, Mass., a city of 24,200 inhabitants, lying near the head of Hoosic River, there arises the most serious contamination along the whole length of the stream. The condition is at times exceedingly offensive, and the local board of health has found it advisable to prohibit the sale of ice from the river and from polluted ponds emptying into it. The condition is well set forth in the reports of the Massachusetts State board of health. The following table of average analyses is taken from the report issued for the year 1900 (p. 330), the water having been taken from the river at Williamstown, a short distance below North Adams.

TABLE XV.—*Chemical examination of water from the Hoosic River at Williamstown, Mass.*

[Averages by years, in parts per million.]

Date of collection.	Turbidity.[a]	Color.[b]	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	D.	1.0	0.187	0.040	0.010	0.306	2.4	102.1	.....
1894	D.	2.3	.265	.111	.009	.157	3.5	107.7	73
1895	D.	2.8	.334	.146	.013	.162	3.9	124.1	81
1896	D.	2.1	.326	.261	.015	.323	4.4	118.3	81
1897	D.	2.3	.273	.125	.008	.252	2.7	99.2	64
1898	D.	2.4	.286	.152	.005	.187	2.6	91.3	58
1899	D.	2.8	.505	.223	.018	.141	5.0	123.7	69
1900	D.	2.4	.436	.328	.026	.146	4.7	118.5	65

[a] "D." is a term used to indicate the general appearance of the water, and means "decided."
[b] Determined according to Nessler standards.

In the above table it is of interest to note the increase from year to year in the ammonias, nitrites, and chlorine, indicating unmistakably the increase in pollution from North Adams, along with municipal growth.

The Hoosic River is therefore a stream which becomes a troublesome nuisance almost at its starting point, and passes through Vermont into New York State in a badly damaged condition. During

the long stretches through New York it improves in quality through oxidation of its organic contents and sedimentation of its suspended matter, and, in spite of the contamination it receives at various points, enters the Hudson probably in better condition than when it crosses the New York-Vermont State line. It is the clearest case of interstate pollution which we have yet considered.

Next above the Hoosic is Batten Kill, which is one of the most valuable power streams tributary to the Hudson. It has a drainage area of about 450 square miles, and the average flow has been roughly determined at about 280 cubic feet per second.

The important centers of population along the river are Greenwich and Salem, which have 1,869 and 3,191 inhabitants, respectively. Neither of these places has a public sewerage system, yet pollution of the river from these points is well marked.

It is a surprising fact that nearly all of the towns and villages lying east of the Hudson in New York seem to be unprogressive, many of them having decreased in population during the last decade. Pollution is therefore not a growing danger in the eastern tributaries, and the water which flows from them into the Hudson is pure as compared with that of the main river.

WESTERN TRIBUTARIES OF THE HUDSON.

Pollution upon the western basin of the Hudson is far more serious than that on the east. The facts concerning the important rivers joining the main river from the west are given in Table XVI

TABLE XVI.—*Western tributaries of Hudson River.*

Stream or branch.	Number of pollution points.	Number of sewerage systems.
Rondout Creek	3	None.
Wallkill	16	3; two doing considerable damage.
Esopus Creek	8	1; part of Kingston system.
Catskill Creek	4	None.
Kaaterskill	6	Do.
Hannacrois Creek	None.	Do.
Norman Kill	2	Do.
Mohawk River. (*See* special discussion below.)		
Anthony Kill	1	1
Fish Creek	2	2
Sacandaga River	3	None.
Indian River	None.	Do.
Cedar River	None.	Do.
Rock River	None.	Do.

Catskill and Esopus creeks, Wallkill River, and Rondout Creek have during the last few months received the attention of the engineering corps of the water department of New York City in cooperation with the Division of Hydrography of the United States Geological Survey. The various drainage areas have been examined, and gaging stations have been established in the streams at convenient and important points.

RONDOUT CREEK AND WALLKILL RIVER.

Entering the Hudson at Kingston is Rondout Creek, which drains an important area in New York and a few square miles in New Jersey. Its principal tributary is the Wallkill, whose drainage area is described in Water-Supply and Irrigation Paper No. 65, pages 71 and 72. At New Paltz, N. Y., a gaging station has been established, and the current-meter measurements that have been made at that place since July, 1901, are reproduced upon pages 72 and 73 of the above-mentioned report.

The principal branch of the Wallkill is Shawangunk Creek. A large amount of sewage enters the main river, and of late it has increased markedly. The principal foci of pollution are at New Paltz, Modena, Gardiner, Wallkill, Walden, Montgomery, Goshen, Middletown, Warwick, New Millford, Hamburg, Deckertown, and Florida. At Middletown (a manufacturing and dairy center) there has been established a sewerage system which discharges into a small tributary of the Wallkill a total of about 865,000 cubit feet of sewage per day. The damage arising from this practice has been so great that it was made the subject of a special investigation by the State board of health of New York. In the twelfth annual report of that body is an account of the investigation, written by Mr. Charles C. Brown, formerly a professor at Union College, Schenectady. A part of Professor Brown's report reads as follows:

> The condition of the stream in the future, if left unattended to, will become rapidly worse, for the amount of pollution entering the stream is rapidly increasing. The sewerage system of the city of Middletown is practically but two years old [1891] and the proportion of houses connected with the system is still quite small. * * * Additional sewers are put in at frequent intervals and the city is steadily increasing in population. * * *
>
> This makes early attention to the improvement of the stream absolutely necessary.
>
> As far as Mohegan Brook is concerned, the trouble could be remedied by constructing an outlet sewer to Wallkill River. I believe the river is not large enough to take care of the amount of sewage discharged from the main sewer without the production of nuisance. Villages along the course of the Wallkill below Middletown are discussing the propriety of using the water for domestic purpose.

Since the date of this report, Middletown has increased to a city of 14,552 inhabitants, a gain of 21 per cent over the returns for 1890. The average daily water consumption is 2,000,000 gallons, and Mohegan Brook has been condemned by the courts as a sewage course, making it necessary for the city to provide a sewage-purification plant.

At Goshen the pollution of the small creeks which run through the village is remarkable. In a report made to the State board of health in 1890 Professor Brown stated:

> This brook at present receives much drainage from houses and business blocks in the village and nearly all the street drainage. But the headwaters of one branch of the stream furnish the water supply for the village, and what is left forms only a small brook, which must become very foul during ordinary seasons when there are no frequent heavy showers to flush it out. On my last visit I found the brook in this foul condition, throughout both its main branches in the village. * * *

I have no doubt that the condition of this brook is responsible to a large extent for the epidemics of zymotic diseases to which the village seems to be subject.

A water and sewerage system has been installed at Walden, a thriving dairying center of 3,147 inhabitants. The total daily water consumption is 80,000 gallons, but as the "combined" system of sewerage has been installed the discharge into the Ten Broeck and Wallkill is considerably more than the water consumption in stormy seasons.

Deckertown, N. J., having a population of 1,306, has installed an excellent water-supply system, and although no sewers have yet been laid a large amount of pollution enters the Wallkill. This forms another opportunity for future trouble arising from interstate pollution. The difficulties of regulating the New Jersey end of the watershed were recognized in the report of the engineering committee of the Merchants' Association of New York upon the Water Supply of the City of New York (p. 78). It was regarded as a "serious complication" in the way of adopting the Wallkill water for the city of New York, although these complications were recognized as due as much to other features of interstate regulation as to pollution.

Chester and Montgomery, villages of 1,250 and 973 inhabitants, respectively, are supplied with water systems, and the pollution of the river is by private drains and contaminated run-off water only.

New Paltz, a village of 1,022 inhabitants, furnishes a surprising amount of contamination, even though it possesses no system of sewerage. Plans were approved by the State authorities for such a system October 27, 1892, which provided for the ultimate disposal of the sewage in Wallkill River, with three main points of discharge. Although almost a decade has passed the system has not been laid, and in the interim extensive private sewers have been laid into the Wallkill in defiance of the State authorities.

ESOPUS CREEK.

A description of the drainage area of Esopus Creek appears upon page 63 of Water-Supply and Irrigation Paper No. 65, and current-meter discharge measurements which have been made at Kingston since July, 1901, are reported upon pages 64 and 65 of the same paper.

On Esopus Creek above the city of Kingston there is only incidental pollution from a few small hamlets, the effects of which upon the river are not important. At Kingston there is a system of sewerage, a part of which discharges directly into the stream. Previous to the installation of this system the State board of health sent its consulting expert, Professor Brown, to examine into the question of probable results of such installation, with especial reference to its effect at Saugerties, where at that time the water was used for drinking purposes by about 900 mill hands. A consideration of the ice industry and the damage that it would probably suffer by the installation of the sewers was included. After determining the physical characteristics of the river with reference to its natural advantages for assisting the process of

sedimentation, and taking into consideration the distance of the proposed outlet above Saugerties, Professor Brown made no very direct statement of the probable effect of Kingston's sewage, but finally recommended that all the sewage from the west end of the city be dumped into Rondout Creek, where it would be conducted more directly to the Hudson. This suggestion was not followed when the sewerage system was laid, and the results have been marked in Esopus Creek, so that it became necessary for the city of Kingston to construct a sewage purification plant. When that part of the system now under construction has been completed it will properly dispose of the sewage from two of the nine wards now discharging into Esopus Creek.

CATSKILL CREEK.

A description of the drainage basin of Catskill Creek appears upon page 61 of Water-Supply and Irrigation Paper No. 65. The records of current-meter measurements of the stream at South Cairo, N. Y., are set forth upon page 62 of said paper. The Catskill, with its principal branch, the Kaaterskill, is another of the western tributaries of the Hudson that is damaged only slightly by pollution. Here and there are small villages along the banks, none of which have sewerage systems, but which contribute manufacturing wastes and private-drain sewage in appreciable amounts, yet which as a whole have no marked effect upon the character of the water. Catskill, a city at the mouth of the river, is the only large place on it, and the pollution from there is carried quickly into the Hudson.

Hannacrois and Coeyman creeks and Norman Kill are not important from the standpoint of pollution.

MOHAWK RIVER.

This great western arm of the Hudson is nearly as widely known as the main river itself. The valley of the Mohawk was made famous in colonial times by Indian wars, and its beauty and the fertility of its land made it a favored line of western travel along which New England emigrants passed or within which they settled according to their tastes and resources. Cities along the banks of this river have grown into prominence, especially since the opening of the Erie Canal, and it is a favored section of the country, which is generally regarded as continuously prosperous.

Under the authority of the United States Geological Survey and the New York State engineer and surveyor, the Mohawk has been studied as has no other tributary of the Hudson. The results of this work are recorded in the Twentieth Annual Report of the Survey and in the State Report by Edward A. Bond, State engineer, made December 1, 1901, entitled Report on the measurement of the volume of streams and the flow of water in the State of New York.

According to the latter report the drainage area of the Mohawk is 3,400 square miles. Results of measurements of flow at a station

A. A LAKE IN THE CATSKILL MOUNTAINS AT THE HEAD OF THE CATSKILL RIVER, NEW YORK

From photograph in possession of American Museum of Natural History, New York City.

B. WINNISOOK LAKE, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

located at the New York State feeder dam, 4 miles below Schenectady, are expressed in the following diagram:

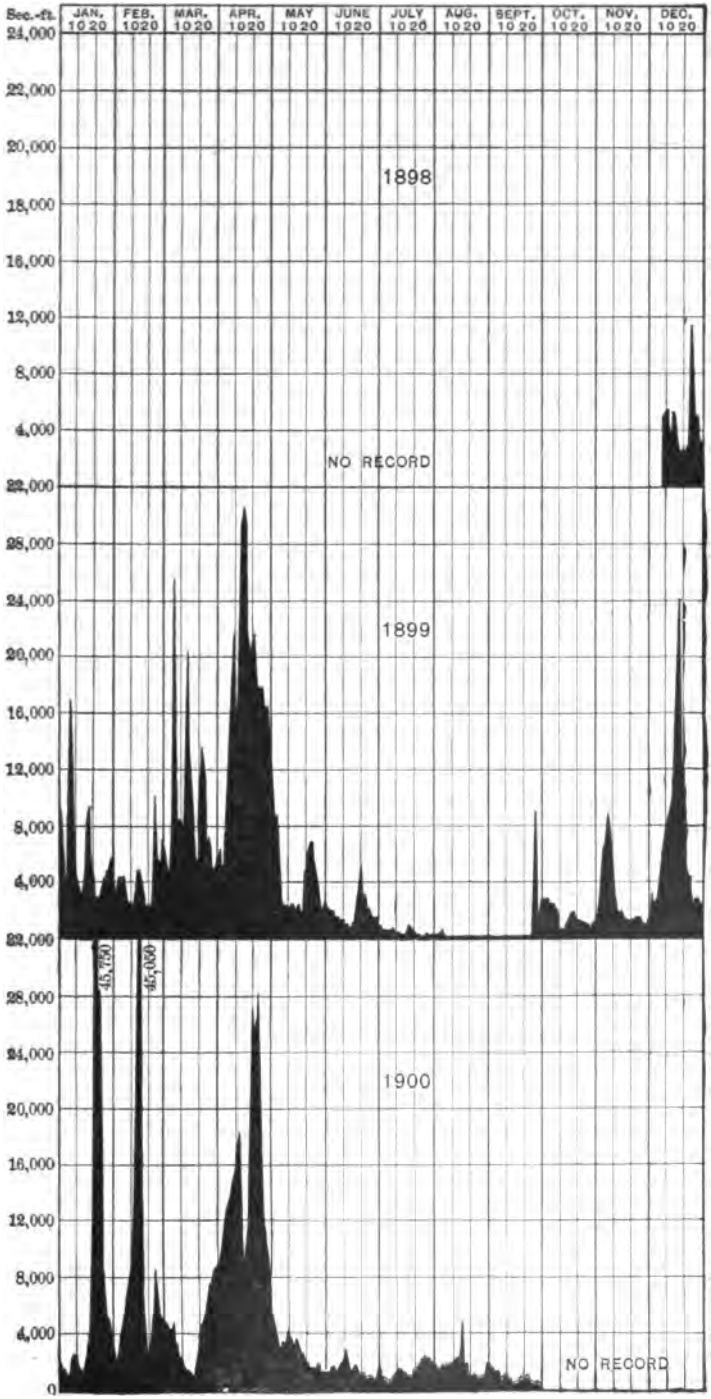

FIG. 2.—Discharge of Mohawk River at Rexford Flats, N. Y., 1898–1900.

Similar measurements were made at Little Falls, Herkimer County with results expressed as follows:

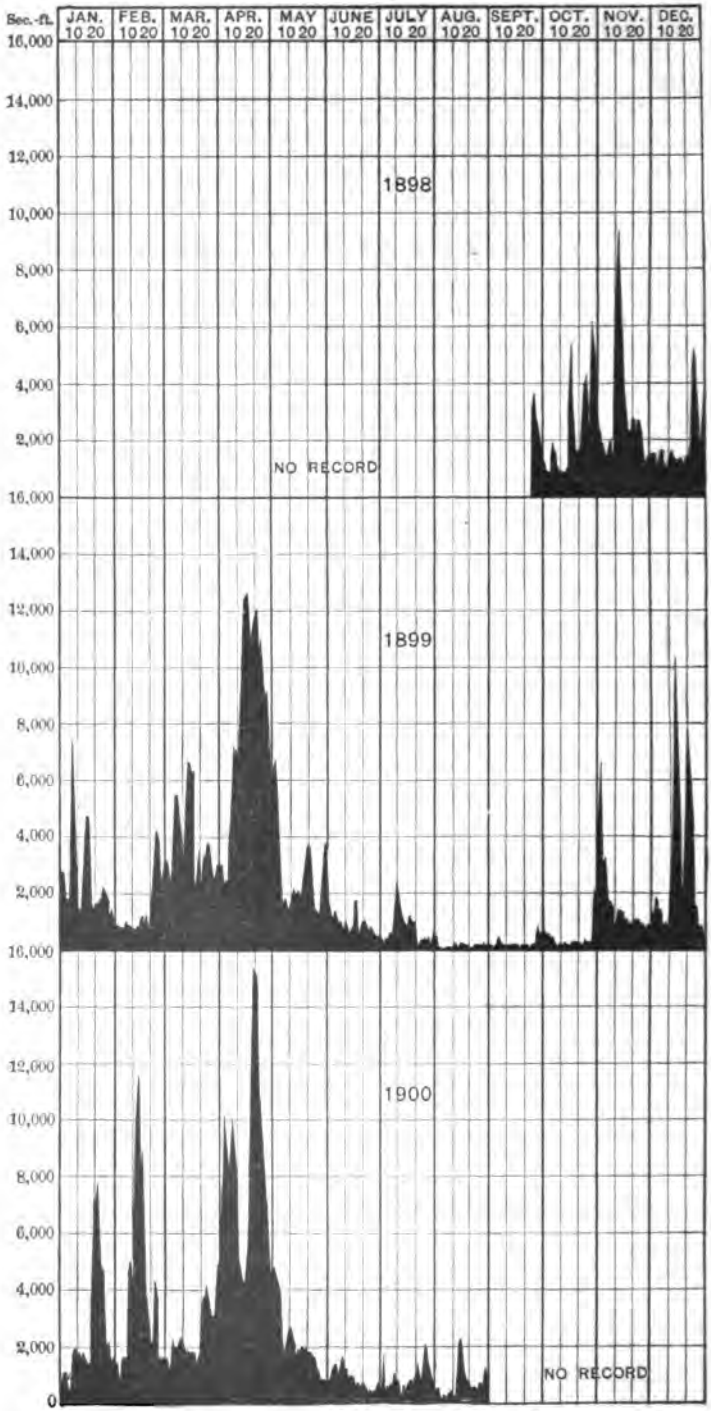

FIG. 3.—Discharge of Mohawk River at Little Falls, N. Y., 1898-1900.

The principal tributaries of the Mohawk are Schoharie Creek, with a drainage area of 974 square miles, East Canada Creek, draining 285.7, and West Canada Creek, the basin of which covers 584 square miles. This leaves to the main river and minor tributaries a drainage area of about 1,557 square miles. The centers of population on the Mohawk proper, from the point of view of pollution, are set forth in Table XVII:

TABLE XVII.—*Centers of population on Mohawk River.*

Name of municipality.	Population.		Water supply.	Sewerage system.	Sewered population.
	1890.	1900.			
Schenectady	19,902	31,682	Yes	Yes	31,682
Amsterdam	17,396	20,929	do	do	20,929
Fonda	1,190	1,145	do	do	1,145
Canajoharie	2,089	2,101	(a)	(a)	
Fort Plain	2,864	2,444	Yes	Yes	2,444
Nelliston	721	634	(a)	(a)	
St. Johnsville	1,263	1,873	Yes	No	
Little Falls	8,788	10,381	do	Yes	10,381
Herkimer		5,555	do	do	5,555
Mohawk	1,806	2,028	(a)	(a)	
Ilion	4,057	5,188	Yes	Yes	5,188
Frankfort	2,291	2,664	No	Partial	
Utica	44,007	56,383	Yes	Yes	56,383
Rome	14,991	18,343	do	do	18,343
Fultonville	1,122	977	No	No	
	120,422	162,277			152,000

a No returns.

The city of Schenectady, the first above Cohoes, is an important manufacturing center. It is provided with water from wells outside the city limits, a new supply which was installed when the city was

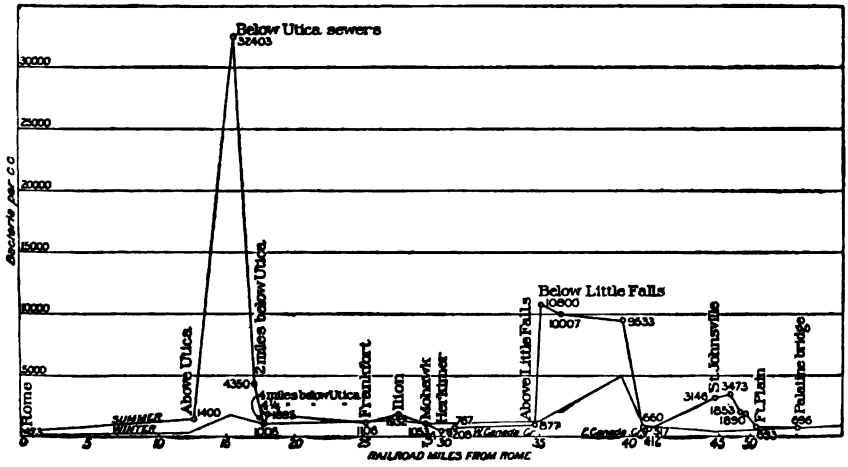

FIG. 4.—Diagram showing extent of pollution at various places along Mohawk River.

obliged to give up the use of the raw water from the Mohawk because of pollution from the cities above. There is also established a separate system of sewerage, from which, according to rough measure-

ments, there are poured into the river 6,000,000 gallons of raw sewage daily.

Amsterdam, a short distance above Schenectady, is also provided with a separate system of sewerage. The small villages of Fort Hunter, Fultonville, Fonda, Canajoharie, Fort Plain, and Nelliston follow in the order stated, each adding its increment to befoul the water of the Mohawk. At Fonda and Fort Plain the sanitary and storm sewers pour considerable sewage into the river, while at the other places there is only the incidental pollution common to unsewered towns.

At St. Johnsville there is provided a double system of water supply, one part of which is for domestic purposes and the other, drawn from a local creek, for fire and domestic purposes. The filthy impregnation of the soil is immense, and the report of the secretary of the local board of health states that, while the amount of sewage flowing into the river has not been determined, there is "plenty of it."

Little Falls has established a combined system of sewerage, which has been extended throughout the corporate limits. Herkimer has a separate system, which discharges about 200,000 gallons of raw sewage daily. At Ilion sewers have been extended practically throughout the corporate limits, and from them about 300,000 gallons are poured into the Mohawk. Farther up on the river is the large city of Utica, grossly polluting the river, and finally Rome, the sewerage system of which constitutes the head of pollution.

TRIBUTARIES OF MOHAWK RIVER.

Cobleskill is the only important point of pollution upon Schoharie Creek, while West and East Canada creeks have not at the present time sufficient pollution to warrant attention here.

The foulest branch of the Mohawk is Cayadutta Creek, a small stream entering the Mohawk from the north at Fonda. The nuisance occasioned by sewage from Gloversville and Johnstown has been of sufficient importance to demand a special investigation by order of the governor of the State of New York.

The following extracts are taken from the Eighteenth Annual Report of the State Board of Health of New York (pp. 85–100):

The undersigned residents of the city of Johnstown, N. Y., respectfully beg to present to your attention the unwholesome condition of a certain portion of this city, situated along East Main street and near the foot of Chase street, consisting of low, marshy land, having communication by a small stream crossing Chase and East Main streets, known as Prindle Creek, with Hale Creek, a large stream flowing for some distance parallel to East Main street, and about 350 feet distant therefrom, and emptying into Schiver's Pond, the waters of which flow into Cayadutta Creek and thence into the Mohawk River at Fonda, N. Y., 4 miles to the south. Into this locality and into the said Prindle Creek—the waters of which are very low during the summer season at the point where said creek crosses East Main street—empties a sewer about 12 inches in diameter, running

A. AUSABLE RIVER, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

B. DEVASEGO FALLS, SCHOHARIE RIVER, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

through a portion of East Main street west of said Prindle Creek, which conveys sewage from the houses along that portion of East Main street and from the houses along that portion of Fon Clair street, which intersects East Main street, being about 35 in number. Into Hale Creek, a short distance to the northwest, and at a point within 250 feet of the residences along said East Main street, empties another sewer of the same size, which conveys sewage from the houses and business places along the remaining portion of East Main street west of Prindle Creek, and from the houses on Glebe and a portion of East State street, which intersect said East Main street, in all being about 150 in number. These sewers have been laid a number of years, and their outflow has been recognized and pronounced by the local board of health to be a public nuisance, and orders have been issued by said board for the abatement of the nuisance. Into said Prindle Creek and the territory aforesaid at or near Chase street also empties a sewer pipe about 14 inches in diameter, running through Chase street and other streets to the south thereof, and which conveys the sewage from the houses on Prospect street, Whitmore avenue, East Clinton, Cady, and East Montgomery streets, a part of East State street, and a part of Fon Clair street. The three sewers mentioned convey all the sewage from the houses and business places in the southeastern portion of the city, comprising in all about 500 in number. The outlet of the said Chase street sewer is within 400 feet of the public school on East State street, at which there is a daily attendance of about 300 pupils.

The condition of affairs in this portion of the city has been frequently, during the past two years, called to the attention of the local board of health and the common council of the city, as the extracts from their minutes of proceedings hereto annexed and made a part of this petition will show, and although they have frequently taken the matter into consideration, no steps have been taken to correct or abate the nuisance and relieve the residents of that portion of the city.

The territory in the neighborhood where these sewer deposits are made is surrounded by residences of the better class, most of them recently built, and those along East Main street, east of the Prindle Creek, which number thirty-five, have thus far been unable to get any sewerage, because it is alleged that the bed of the Prindle Creek is not low enough to permit of sewering into that stream, and the local authorities have thus far refused to provide any other method.

In this connection it may be well to state that all the sewage of the city of Gloversville, and most of that of the city of Johnstown, is discharged, directly or indirectly, into the Cayadutta Creek, and thence into the Mohawk River at Fonda, without being treated, and it has been suggested that the territory referred to in this petition can be properly sewered by a pipe running through the bed of Schrivers Pond into Cayadutta Creek, and it is apparent that no special harm will come from this additional quantity of sewage thus disposed of. The undersigned, who live within the pernicious influence of this nuisance, which is admitted to be a nuisance by the local authorities, respectfully represent that the situation demands immediate action, that a loathsome stench pervades the locality under certain conditions of temperature, and that already, during the hot weather of this summer, this stench has been prevalent. Sickness has occurred which has been attributed by physicians to this cause. The nuisance increases in gravity every year, while the sewage more deeply impregnates and pollutes the soil.

The undersigned beg your excellency to lay the matter before the State board of health with instructions to investigate it and adopt such measures as shall without delay put an end to this nuisance. Efforts have been made for two years past without avail to accomplish this object, and we appeal to your authority to set in motion the measures which shall promptly relieve us of a distressing and dangerous pest.

[Signed by thirty-eight residents of Johnstown, N. Y.]

The report of Dr. F. C. Curtis, consulting expert, who went to investigate the conditions alleged in the above petition, is as follows:

Johnstown is supplied with sewers which provide for the house waste of a considerable portion of the city, all emptying into Cayadutta Creek. East Main street, referred to in the petition, is a continuation of Main street into a more recently built part of the city. The topography is such that it is impossible for a sewer from this section to connect with already existing sewers, as it lies at a considerably lower level. East Main street, which is built up with detached residences of a good class for some distance, has no sewerage outlet, the residences depending upon cesspools for their waste. To the southeast of this street the ground rises rather abruptly, and several streets, more or less built up, are laid out upon it. Coming down from this territory is a small stream, Prindle Creek, which traverses East Main street obliquely and flows across low meadows to Cayadutta Creek, or, rather, in its course, through Schrivers Pond. This is the natural drainage medium for the southeastern area of the city. The stream as I saw it, after prolonged rain, was a considerable one, but it soon dwindles to a very moderate flow of perhaps 10 gallons per second. Just before it reaches East Main street it crosses Chase street, which extends up the abrupt hillside for a few blocks and terminates at the bottom, as do all its parallel streets, in East Main street. In this Chase street is a recently laid 12-inch tile sewer which collects and carries off the sewage not only of Chase street, but of a number of lateral streets which branch into it. This sewer, with no provision for flushing it, terminates beneath a small bridge in the little stream, and as the volume of this stream is inadequate to carry away the sewage thus turned into it, this deposits directly at the sewer outlet and along its course, especially in the low meadow land on the other side of East Main street. It becomes a tortuous, uneven, open sewer, and by means of its improper use a serious nuisance, inevitably filling the surrounding atmosphere with offensive and unwholesome odors. There is no question of this, from my own observation, nor on the part of the health officer and citizens with whom I conferred.

In the Nineteenth Annual Report of the State Board of Health (pp. 74–76) Prof. Olin H. Landreth, who was engaged by the city of Johnstown to investigate the matter, reports in part as follows:

The only manufacturing waste of sufficient amount to warrant consideration in conjunction with the matter of sewage is the tannery and leather-dressing waste and refuse. There are at least 18 establishments in the city engaged in this business, employing in the aggregate about 750 men when in ordinary operation.

Returns were duly received from the majority of the concerns, representing over two-thirds of the total number of men employed and three-fourths of the total output, and means were taken to secure the best estimates possible for the remainder of the plants. The aggregate exhibit for all the plants representing those covered by both returns and estimates is as follows:

Number of men employed		746
Weight of hides per annum	pounds	5,600,000
Gallons of water per diem		150,000
Weight of lime per annum	pounds	725,000
Weight of alum per annum	do	230,000
Weight of salt per annum	do	1,500,000
Weight of oil vitriol	do	45,000
Weight of copperas per annum	do	6,000
Weight of bluestone per annum	do	600

Weight of muriatic acid	pounds	4,000
Weight of soda ash	do	50,000
Weight of hyposulphate soda	do	18,000
Weight of bichromate potash	do	12,000
Weight of fish oils	do	500,000
Weight of flour	do	100,000
Weight of logwood	do	1,500,000
Weight of Brazil wood	do	21,000
Weight of fustic	do	320,000
Weight of hypernic	do	110,000
Weight of quercitron	do	28,000
Weight of gambier	do	500,000
Weight of anilines	do	1,000
Weight of lactic acid	do	1,100
Weight of sal soda	do	15,000
Weight of alder wood	do	7,000
Weight of egg yolk	do	105,000

Accurate statistics of the amount of leather produced from the hides could not be obtained, but from estimates made by several individuals conversant with the business it is safe to conclude that the weight of leather, independent of the materials which it finally contains as filling and coloring matter, is less than one-half the weight of the hides used, indicating about 3,000,000 pounds per annum of refuse animal matter, chemical preservatives, and filth. Certain portions of this refuse material are preserved for utilization as by-products, but there is good ground for the estimate that not less than one-third of the above amount, or 1,000,000 pounds, and quite possibly 2,000,000 pounds, of the most offensive parts of this refuse from the hides is discharged into the creek. The returns show that of the water used by the tanneries less than 1 per cent is taken from the city supply, the remainder being about equally divided between creek water and deep-well water.

Of the chemicals tabulated, it is not to be inferred that all pass into the creek, nor that all that does pass enters the creek in the chemical form in which they are tabulated. A considerable portion of the chemical and coloring matter used is carried away in the leather, and much of what remains undergoes neutralization and other chemical changes before entering the creek, and also to some extent after entering the creek, as not all the establishments employ the same methods and chemicals nor discharge their refuse at the same time. The coloring and filling materials are largely retained in the leather, while smaller proportions of the active chemicals in the aggregate are so retained, and this latter class of materials forms the larger portion of the whole. Of the 5,800,000 pounds of chemicals and other materials used, not including the hides, my inquiries and study of the question lead to the conclusion that not less than 3,000,000 pounds are discharged after use into the stream either in solution or suspension (except as to the spent time), widely changed or neutralized, highly polluted and diluted. If to this we added 1,500,000 pounds per annum refuse from hides, estimated above, the aggregate of animal refuse, chemical, coloring matter, etc., discharges into the creek, independently of the water with which it is diluted, will be 4,500,000 pounds per annum, or 15,000 pounds per working day.

The general effect of pollution in the Mohawk and Hudson, from Rome to Albany, has been carefully studied by Prof. C. C. Brown and Dr. Theobald Smith, under the authority of the State board of health, and a statement of the results is made in the reports for 1892

and 1893, pages 531–547 and 680–736, respectively. Chemical examinations of water from Hudson and Mohawk rivers through Schenectady to Cohoes were made by Prof. William P. Mason and Willis G. Tucker, while the biological and engineering work was under the charge of Messrs. Smith and Brown, respectively.

The investigation shows in a striking manner the effect of pollution upon the waters of the Mohawk. Starting above Rome, where the water is practically normal both from a chemical and bacteriological standpoint, the samples taken at different points along the river to the mouth show greater or less pollution according as the points from which they were taken were near to or some distance below the outlets of sewers of the different cities. By way of illustration, the series of chemical analyses made by Prof. William P. Mason is reproduced in Table XVIII, taken from the Twelfth Annual Report of the State Board of Health of New York, pages 544–545.

TABLE XVIII.—*Pollution at different points on Mohawk and Hudson rivers.*

[The analyses are in parts per 100,000.]

	Chlorine.	Nitrogen as nitrites.	Nitrogen as nitrates.	Free ammonia.	Albuminoid ammonia.	Required oxygen.
At Rome	0.25	0.0000	0.0206	0.0045	0.0090	0.440
1. Just above Schenectady	.40	.0004	.0202	.0040	.0200	.485
2. Just below Mill Creek	.50	.0004	.0202	.0065	.0200	.440
3. Schenectady intake	.45	.0004	.0289	.0050	.0170	.425
4. Below New York Central bridge	.45	.0004	.0289	.0045	.0175	.430
5. Just below main Schenectady sewer	.45	.0005	.0288	.0040	.0195	(a)
6. Between Delaware and Hudson and highway bridges	.40	(a)	.0288	.0075	.0155	(a)
7. Opposite lower ice houses	.40	.0004	.0244	.0060	.0180	.395
8. One mile above aqueduct dam	.40	.0002	.0246	.0050	.0140	.395
9. Crest of aqueduct dam	.40	.0002	.0246	.0030	.0140	.355
Dunsbeck's ferry	.40	.0005	.0288	.0080	.0160	.330
10. Crest of Cohoes dam	.40	.0002	.0246	.0060	.0210	.355
11. Below Cohoes Falls	.40	.0003	.0290	.0180	.0255	.375
12. Waterford intake (Hudson River)	.25	.0000	.0123	.0045	.0170	.830
13. Troy intake	.25	.0000	.0041	.0040	.0150	.840
14. Below State dam (ebb)	.25	.0000	.0123	.0065	.0185	.610
15. A (ebb)	.25	(b)	.0123	.0040	.0140	.680
16. B (ebb)	.25	(b)	.0164	.0060	.0155	.620
17. C (ebb)	.25	(b)	.0164	.0090	.0180	.640
18. D (ebb)	.25	(b)	.0123	.0060	.0165	.670
19. E (ebb)	.25	(b)	.0123	.0060	.0160	.680
20. F (ebb)	.25	(b)	.0123	.0050	.0175	.685
21. G (east shore), ebb	.25	.0000	.0041	.0060	.0240	.900
22. G (middle), ebb	.25	.0000	.0041	.0050	.0215	.670
23. G, Albany intake (ebb)	.25	(c)	.0082	.0070	.0200	.570
24. H (ebb)	.30	.0000	.0000	.0115	.0140	.695
25. I (ebb)	.20	(b)	.0041	.0185	.0150	.695
26. J (ebb)	.25	(b)	.0041	.0125	.0160	.705
27. K (ebb)	.25	(b)	.0041	.0130	.0165	.680
28. L, Van Wies Point (ebb)	.25	(b)	.0041	.0115	.0170	.585
29. Below State dam (flood)	.25	.0010	.0000	.0030	.0185	.590
30. A (flood)	.25	.0000	.0041	.0055	.0160	.655
31. B (flood)	.25	(b)	.0000	.0050	.0165	.650
32. C (flood)	.25	(b)	.0000	.0055	.0170	.630
33. D (flood)	.25	.0000	.0000	.0060	.0150	.630
34. E (flood)	.25	.0000	.0041	.0045	.0175	.630
35. F (flood)	.25	(b)	.0000	.0055	.0215	.660
35½. Greenbush intake (flood)	.25	.0000	.0000	.0085	.0195	.675
36. G (east shore) (flood)	.25	.0000	.0041	.0070	.0215	.610
37. Albany intake (flood)	.25	.0000	.0041	.0075	.0185	.600
38. H (flood)	.30	.0001	.0041	.0120	.0205	.605
39. I (flood)	.25	(b)	.0041	.0110	.0185	.605
40. J (flood)	.30	.0002	.0082	.0120	.0170	.610
41. K (flood)	.30	(b)	.0082	.0125	.0170	.655
42. L, Van Wies Point (flood)	.30	(b)	.0082	.0090	.0165	.645

a Lost. b Trace. c Large trace.

With even more striking clearness does the record of numerical determinations of bacteria along the river show the compromising effect of pollution, and the positive tests for fecal bacteria to which the water was submitted by Dr. Theobald Smith make it unquestionably certain that waters polluted by domestic sewage retain the effects of fecal pollution, even beyond the point at which sanitary analysis would show an unpolluted stream.

Table XIX, which gives the results of numerical determinations on the Mohawk River, is taken from the same report as Table XVIII.

TABLE XIX.—*Pollution of the Mohawk River by bacteria, 1891.*

Date.	Number.	Time.	Number of bacteria per c. c.	Average of— Samples.	Average of— Plates.	Remarks.
July 29	1	7.00 p. m.	765	1	2	Rome waterworks dam, above city.
Do	2	8.00 p. m.	473	1	2	Below feeder dam at Rome.
July 30	3	8.45 a. m.	1,400	1	2	Above Utica; below bone works
Do	4	10.15 a. m.	32,403	1	2	Below Utica sewers.
Do	5	11.00 a. m.	4,350	1	2	Opposite Masonic Home, 2 miles below Utica.
Do	6	11.25 a. m.	1,005	1	2	About 4 miles below Utica.
Do	7	11.30 a. m.	1,895	1	2	About 4½ miles below Utica.
Do	8	3.00 p. m.	1,106	1	2	Frankfort, above New York Central station.
Do	9	4.55 p. m.	1,932	1	2	Ilion, below New York Central station.
July 31	10, 11, 13, 14	9 a. m. to 1 p. m.	.....	(a)	.....	Water roily from rain.
August 6	17	2.37 p. m.	1,508	1	2	Opposite canal lock at Mohawk.
Do	18	2.55 p. m.	437	1	2	Opposite Herkimer at lower bridge.
Do	20	3.50 p. m.	298	1	2	West Canada Creek.
Do	19	3.30 p. m.	767	1	2	One-half mile below mouth of West Canada Creek.
July 31 / August 6	15 / 21	2.35 p. m. / 5.40 p. m.	877	2	4	State dam above Little Falls.
July 31 / August 6	16 / 22	4.30 p. m. / 6.15 p. m.	10,800	2	4	Just below foot of falls, Little Falls.
August 7	23	10.00 a. m.	10,007	1	1	About 1½ miles below Little Falls.b
Do	24	12.10 p. m.	9,583	1	2	State dam, 5 miles below Little Falls.
Do	25	2.55 p. m.	660	1	2	Above mouth of East Canada Creek.
Do	26	3.05 p. m.	412	1	2	East Canada Creek.
Do	27	3.15 p. m.	517	1	2	Twenty rods below mouth of East Canada Creek.
August 8	28	10.15 a. m.	3,146	1	2	St. Johnsville, below creek draining village.
Do	29	10.55 a. m.	3,473	1	1	One-half mile below St. Johnsville, below rapids.
Do	30	11.30 a. m.	1,953	1	2	Three miles below St. Johnsville.
Do	31	1.15 p. m.	1,890	1	2	About 2 miles above Fort Plain.
Do / August 11	32 / 33	2.35 p. m. / 11.35 a. m.	883	2	3	Fort Plain, above New York Central station.
Do	34	12.50 p. m.	696	1	1	One mile above Palatine bridge.
Do	35	2.15 p. m.	304	1	1	Just above Palatine bridge.
Do	36	3.00 p. m.	273	1	1	Three-fourths of a mile below Palatine bridge.
Do	37	4.50 p. m.	560	1	1	At Sprakers, above rapids.
Do / August 12	38 / 40	5.20 p. m. / 9.20 a. m.	672	2	2	Three-fifths of a mile below Sprakers, below rapids.
Do	41	2.25 p. m.	164	1	1	Above Cayadutta Creek.
Do	42	2.30 p. m.	2,288	1	1	Cayadutta Creek.
Do	43	2.35 p. m.	306	1	2	One-half mile below Cayadutta Creek.

TABLE XIX.—*Pollution of the Mohawk River by bacteria, 1891*—Continued.

Date.	Number.	Time.	Number of bacteria per c. c.	Average of— Samples.	Average of— Plates.	Remarks.
August 12	44	2.40 p. m.	416	1	2	Three-fourths of a mile below Cayadutta Creek, below rapids, Fonda, and Fultonville.
Do	45	5.20 p. m.	283	2	4	Above Schoharie Creek.
August 14	47	12.40 p. m.				
August 12	46	5.45 p. m.	51	2	4	Schoharie Creek.
August 14	48	12.55 p. m.				
Do	49	8.15 p. m.	331	1	2	Opposite Akin station.
Do	50	3.30 p. m.	276	1	2	One-half mile below Akin.
Do	51	4.25 p. m.	231	1	2	Just above Amsterdam.
Do	52	4.50 p. m.	12,080	1	2	Chuctanunda Creek.
Do	53	4.53 p. m.	11,765	1	2	Opposite Wendell's drug warehouse, Amsterdam.
Do	54	5.06 p. m.	5,408	1	2	Opposite Armour's beef house, Amsterdam.
Do	55	5.13 p. m.	6,562	1	2	Just below Amsterdam.
Do	56	6.20 p. m.	2,904	1	1	One-half mile below last mill in Amsterdam.
Do	57	6.30 p. m.	9,812	1	1	One mile below last mill, Amsterdam, near garbage dump.
Do	58	7.00 p. m.	6,060	2	2	Opposite Cranes village, floating sewage.
August 15	59	9.00 a. m.				
Do	60	9.20 a. m.	1,104	1	2	One mile below Cranes village.
Do	61	11.20 a. m.	1,084	1	2	One-fourth of a mile below Hoffman's ferry.
Do	62	11.45 a. m.	710	1	2	One and one-fourth of a mile below Hoffman's ferry.
Do	63	1.50 p. m.	448	1	1	Above Fitchburg Railroad bridge.
Do	64	2.35 p. m.	656	1	2	Three and one-half miles above Schenectady.
Do	65	4.00 p. m.	1,634	1	2	One-fourth of a mile above Van Slykes Island, above Schenectady.
Do	66	4.45 p. m.	791	2	4	Above Glenville bridge, Schenectady.
August 17	68	10.45 a. m.				
Do	69	11.00 a. m.	444	1	2	Binnekill Branch above Edison sewer.
Do	70	11.05 a. m.	7,276	1	2	Mill Creek.
Do	71	11.10 a. m.	3,836	1	2	Binnekill Branch below Edison sewer and Mill Creek.
August 15	67	4.55 p. m.	1,145	2	4	Opposite waterworks, at intake.
August 17	72	11.20 a. m.				
Do	73	11.21 a. m.	440	1	2	Opposite waterworks, north side of channel.
Do	74	11.22 a. m.	432	1	2	Above New York Central bridge, opposite ice house
Do	75	11.25 a. m.	312	1	2	Below New York Central bridge, opposite ice house.
Do	76	1.30 p. m.	196	1	2	Two hundred feet below sewer outlet; pond, sluggish current.
Do	77	1.50 p. m.	294	1	2	Above Delaware and Hudson Railroad bridge.
Do	78	2.00 p. m.	424	1	2	Below Delaware and Hudson Railroad bridge, opposite ice house.
Do	79	3.30 p. m.	296	1	2	One mile above aqueduct.
Do	80	4.10 p. m.	216	1	2	Aqueduct dam.

a Rejected. *b* Garbage dump, three-fourths mile above the locality of this sample.

NOTE.—Accidents happened to samples below the aqueduct, and reliable results were not obtained.

Table XX gives the results of tests made to determine the presence of fecal bacteria at the Albany water intake, together with the total number of bacteria in the samples.

TABLE XX.—*Pollution by bacteria of water at Albany water intake.*

Date.	Stage of tide.	Number of fecal bacteria.	Number of bacteria. West side. Surface.	West side. Bottom.	Middle channel. Surface.	Middle channel. Bottom.	East side. Surface.	East side. Bottom.
October 29, 5 p. m.	1.10 before low water.	54	2,050	4,020	4,530	4,950	4,430	.....
October 22, 2 p. m.	0.19 before low water.	26	1,180	1,850	2,600	2,430	2,770	.....
October 15, 9 a. m.	0.21 after low water...	22	3,290	3,590	5,170	4,390	8,200	.....
October 1, 9 a. m.	1.08 after low water...	92	3,620	3,620	7,150	6,450	5,400	6,120
October 22, 5 p. m.	1.08 before high water.	82	2,080	3,020	2,260	2,030	1,870	.....
October 15, 1 p. m.	0.53 before high water.	32	2,840	2,730	3,220	3,960	4,170	.....
October 29, 1 p. m.	2.26 after high water..	41	4,250	3,900	4,610	4,700	9,320	.....
October 1, 1 p. m.	0.18 after high water..	26	1,960	2,090	2,950	5,280	4,090	.....

A further investigation of the water supply of Schenectady includes the determination of fecal bacteria, with special reference to *Bacillus coli communi*, the organism which is closely identified with intestinal contents. The localities from which the samples were taken are different, convenient, and favorable points along the Mohawk between Amsterdam and Schenectady. Table XXI gives the results of these investigations, taken from the Thirteenth Annual Report of the State Board of Health of New York, pages 731–732.

TABLE XXI.—*Determination of fecal bacteria in Mohawk water between Amsterdam and Schenectady.*

[The column "Number bacteria" gives the number of bacteria obtained by the gelatin-plate method. The column "Number coli" gives the number of *Bacillus coli communi*, and the column "Number fecal bacteria" gives the total number of the three kinds of fecal bacteria determined.]

Locality.	Number bacteria.	Number coli.	Number fecal bacteria.
DECEMBER 16.—FIRST SET.			
Second lock	18,000	16	25
Below first rapids	20,000	.....	.....
Head Van Slykes Island	9,100	.....	.....
Below Sanders's house	6,800	.....	.....
Above Glenville bridge	22,000	13	19
Intake	13,000	45	49
DECEMBER 24.—SECOND SET.			
Second lock	8,200	8	15
Below first rapids	.....	.....	.....
Head Van Slykes Island	.....	.....	.....
Below Sanders's house	6,100	.....	.....
Above Glenville bridge	5,700	12	12
Intake	5,900	12	12
JANUARY 14.—THIRD SET.			
Opposite Akin, south side of river	16,000	7	7
Just below last Amsterdam sewer	27,000	.....	7
One mile below last Amsterdam mill	25,000	15	22

JANUARY 21.—THIRD SET.

Locality.	Number bacteria.	Nhmber coli.	Number fecal bacteria.
At Cranes village	12,000	3	3
One and one-half miles below Cranes village	16,000	13	13
At Hoffmans ferry	9,000	13	13
One and one-half miles below Hoffmans ferry	15,000	13	17

JANUARY 26.—THIRD SET.

At Fitchburg railroad bridge	18,000	25	29
At second lock	17,000	13	13
Half way from Sanders's house to Glenville bridge	20,000		
Eight hundred feet above Glenville bridge	14,000	16	19
Intake of waterworks	18,000	13	13

SCHENECTADY INTAKE.—DECEMBER 24.

7.15 a. m	3,700	23	31
11.30 a. m	5,900	12	12
4.00 p. m	4,900	31	37

The work outlined above was done in the early years of the last decade, when the science of bacteriology was still in its infancy. Since that time improved methods have shown that the bacteria isolated by Dr. Smith's famous process are not necessarily all fecal bacteria, but that there are other forms which respond to the same test. This does not reduce the weight of Dr. Smith's conclusions in the above case, however; for, taking into consideration the circumstances and conditions attending, there is good reason to believe that the greater part, if not all, of the organisms isolated by Dr. Smith were true fecal bacteria.

ANTHONY KILL.

Running in a general westerly direction from Ballston Lake, through Round Lake, Anthony Kill enters the Hudson at Mechanicville. Aside from the pollution that it receives from this village above the confluence with the Hudson, the only polluting area of importance is the camp-meeting settlement on the western border of Round Lake, and this has been rendered innocuous by the establishment of very satisfactory sewage precipitation works, described on page 371 of Sewage Disposal in the United States, by Messrs. Rafter and Baker. The permanent population of Round Lake is stated as about 400, and in summer, during some days, there are 7,000 people on the grounds. The source of water supply is Round Lake, and into this pond the purified sewage is discharged, but apparently without appreciable effect upon the water.

FISH CREEK.

Entering the Hudson at Schuylerville is Fish Creek, which takes a very irregular northwesterly trend from Saratoga Lake. The country

about the lake is of wide repute, having been at one time probably the most famous resort in the East, and is still holding its own with most of the watering places in the United States.

Saratoga Springs, with a permanent population of 12,409, and Ballston Spa, a village of 3,923 inhabitants, are situated within the drainage area of Saratoga Lake. Both municipalities are supplied with sewerage systems, and the extensive pollution of the lake is accurately described in a petition to the governor of the State of New York, signed by various residents of Saratoga County, from which the following extracts are taken:

The petition of the undersigned residents of the county of Saratoga respectfully shows as follows: That Saratoga Lake in said county is about 5 miles long and about 2 miles wide, and is about 4 miles from the village of Ballston Spa and Saratoga Springs, and that Saratoga Springs is a summer resort, visited by thousands of tourists every summer, and to Saratoga Lake is the chief drive and resort; that said lake has been for a great many years a prominent and attractive resort for fishing, hunting, and boating, and for the past few years offensive odors have arisen from the waters in the said lake near the shores, causing annoyance and breeding disease; that large numbers of fish have been picked up dead along the shores of the lake, and the shores thereof in certain portions are covered with filthy and noxious material, offensive to the eye and giving out offensive odors; that in the opinion of your petitioners, unless measures are taken to prevent the defilement of said lake, and its condition continues to grow worse, all the fish in the lake will be killed, and people will cease to occupy cottages on the shores, and it will cease to be attractive as a summer resort.

That the causes of defilement of the waters of the lake are various; that they proceed from the discharge of the sewage of the villages of Saratoga Springs and Ballston Spa into said lake, and from the discharge into said lake of chemicals and refuse from certain manufacturing establishments located in or near the village of Ballston Spa.

[Signed by 31 residents of the county of Saratoga.] [a]

The extent to which Fish Creek is affected by pollution is so far undetermined. It is probable that the actual damage in the stream is far less than in the lake, due, of course, to sedimentation. The report of Professor Landreth, made in response to the above petition, recognizes the importance of the offense and recommends that judicial proceedings be prosecuted to ascertain the exact amount of nuisance, and the responsibility therefor.

As a result of the action above outlined, the sewage-disposal systems of Saratoga Springs and Ballston Spa have been condemned and sewage purification must be established by both municipalities.

Victory Mills, a village of 795 inhabitants, is situated upon the creek a short distance above Schuylerville. It has no water nor sewerage system, and contributes an inappreciable amount of pollution to the river.

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[a] Nineteenth Annual Report of State Board of Health of New York, p. 107.

DAMAGE TO WATER RESOURCES OF HUDSON RIVER SYSTEM BY POLLUTION.

It is not possible to estimate, with any considerable degree of accuracy, the amount of damage that has been done to the Hudson River system by sewage pollution. This is true, not because such damage is of incalculable extent nor because there is a lack of data, but by reason of the fact that there are so many features to be considered in this large area, and so many modifying conditions, that deductions must be drawn simultaneously from many different points of view and the resulting composite conclusions must ever be to a large degree modified by personal opinion. If we survey the different tributaries and note the points of contamination and the extent thereof we shall very soon realize that in nearly every stream there is such enormous dilution and so many opportunities for sedimentation that, taken individually, there is hardly any reason to believe that any material damage has been done. Going further, we look for the results of the concentration of all this sewage into a main water course, and find that that course is the middle section of the Hudson, which, as has already been stated, is of more value to the State of New York in its present contaminated condition than if regulations were enforced which would maintain its purity.

Summing up the total amount of raw sewage emptying into the river system, and taking into account the vast number of people living in cities along its banks, it would appear that the pollution is sufficient to entirely destroy the value of the water course and make the surrounding country an undesirable locality for many purposes; yet when consideration is taken of the fact that the amount of run-off water in this basin is sufficiently large to dilute this sewage so that in places it almost escapes detection, the actual damage done appears to be greatly modified, or, in the opinion of many, it becomes almost nil. This very question opens all the contested points concerning the amount or percentage of pollution within the safety limit; the idea of self-purification of rivers is brought to the front and with it questions as to the effect of the contour of river beds and the existence of artificial works, such as dams and mill ponds. In the discussion of different points of pollution in the preceding pages instances were cited of local nuisances due to contamination at near-by points, which contrast in a very confusing manner with the statement that off Poughkeepsie, where we might expect all this filth to give evidence of itself, Dr. Drown found what was, from a chemical standpoint, a very fair potable water.

In the results of bacteriological examination of the Mohawk by Dr. Theobald Smith we have seen that the high percentage of bacteria that appeared in samples of the water taken below cities gradually fell off as the points of pollution were left farther and farther behind.

When these results were plotted geometrically there appeared a series of crests and troughs in the curve, the distance between the crests corresponding exactly to the distance between points of pollution, measured at the same scale.

All these apparent paradoxes have their logical explanation, the disputed points being confined largely to minor details. It would, indeed, be an endless and unprofitable task to attempt to reconcile the different features which modify conclusions, and it will not be attempted here.

It is proposed to point out the losses and damages for which pollution is responsible, confining qualifications thereof to a few well-attested instances in which it is apparent that river pollution is less expensive than the avoidance of it. There are many cases in which the cost of purifying sewage before turning it into a river, or the expenses entailed in securing some other place of final disposal, far exceed the cost of providing a pure-water supply from highland or other sources, and in such cases it is manifestly better, if there are no other rights to be considered, to use a stream as a sewage course rather than a source of water supply. Such instances should be treated from the standpoint of general public economy, every apparent consideration being taken into account.

WATER POWER.

It has already been stated that damages to water-power interests in the Hudson drainage area are not, comparatively speaking, large. There are, indeed, a few mills that have been obliged to give over the use of river water in various manufacturing processes because of impurities it contains, but the loss entailed does not appear to be serious. Neither does the future promise any remarkable change in this respect. Without doubt, new sewerage systems that are approved from time to time by the State commissioner of health will be provided with means of purification if the installation of such systems promises any great increase of river pollution.

There are few cases in which mill ponds have become public nuisances by reason of deposits of sewage upon the banks, but such will be taken up under the consideration of damages to realty values.

ICE.

The Hudson River ice crop has a national reputation, yet few people realize its extent, and fewer can locate the points at which storage houses are gathered. In the April number of the Ice Trade Journal for 1901 nearly four pages are occupied by a list of ice houses along this river and a statement of the amount stored in each. The crop depends entirely upon the winter's temperature, and the amount of ice that is available for harvest varies accordingly. During the winter of 1900–1901 there were cut and stored 4,606,800 tons, this being

the largest crop ever gathered. During the preceding year there were stored only 1,430,670 tons, which, although large in itself, seems small when compared with the enormous amount harvested in the succeeding winter.

There seems to be no special center for the industry, the field extending all along from Schuylerville, past Cohoes, Waterford, and Troy, nearly down to the limit of salt water influence. On Rondout, Esopus, Catskill and other creeks there are large ice houses, and from certain lakes, such as Rockland, Croton, and Mahopac, there is gathered a considerable harvest, 230,000 tons being cut from these three lakes during the past winter. By far the greater amount, however, comes from the main river.

Sufficient data have been presented to show how great, even in the most unfavorable years, is the value of the Hudson River as a source of ice supply. It has been stated in preceding pages that pollution in a river is a damage to the ice industry, and that, even though recent research indicates that the typhoid bacillus does not survive during long periods when locked in ice, public use of this commodity when polluted with sewage will not be tolerated. A little reflection will show how worthless is a polluted stream or lake as a source of ice supply. Modern biology has found means effective for the purification of contaminated water. Such means are not applicable to ice, and thus polluted ice is, or should be, a total loss; it can not be sterilized nor in any way relieved of its dangerous qualities. With the ever-increasing use of this article in and upon our food there is a necessity that greater care be taken as to its source. The absence of typhoid fever bacilli in polluted ice is by no means a guarantee of its safety for domestic use. The dangers are well expressed in the following paragraph, taken from an article by James M. Anders, M. D., LL. D., of Philadelphia:

> While I shall endeavor later to emphasize the potency of impure water, especially when bacterially contaminated, in causing certain diseases, I desire at the outset to insist that the deleterious and devitalizing effect of imbibing such water, upon the general health of the community, is practically inconceivable. By lowering the resistance to that large class of infectious diseases, its indirect influence as a causative factor must be considerable, not to speak of the suffering occasioned by the habitually depressed and weakened systemic condition thus engendered. Much inconvenience and ill health caused by impurities in the drinking water originates primarily from the alimentary tract, and is due to gastric and intestinal disturbances. The ingestion of contaminating materials may be a cause of dyspepsia or diarrhea, and most probably also renders the system receptive to the invasion of the bacillus coli, the bacillus of Shiga, and other pathogenic organisms, and this *quite independently of any pollution of the drinking water by the disease-producing germs themselves* [italics by M. O. L.].—American Medicine, March 29, 1902, p. 503.

Above Albany were cut, last season, 502,700 tons of ice. By far the greater part of this was taken below the mouth of the Mohawk and in that river itself. At Crescent, a bend in the Mohawk, a few miles

below the outlet sewers of Schenectady, the reports show a total crop of 163,000 tons. From the mouth of the river, where the pollution from Cohoes, Waterford, and Lansingburg is most dangerous, were taken 200,000 tons more, and below Troy and Watervliet the harvest amounted to about 75,000 tons. The water taken from practically these same points was found by Dr. Theobald Smith to contain fecal bacteria.

South of Albany, within 4 miles from the outlets of the sewers of that city, and at Rensselaer there were harvested during the season of 1901 over 300,000 tons of ice. The water in the Hudson above Albany is now being purified for potable use in that city, because the citizens found by costly experience that it could not be used in its raw state. What, then, must be the condition of that water shortly after the sewage of 101,617 more persons has been added to it?

In spite of the conditions outlined above, this river is the principal source of ice supply for the great metropolitan area, and although the value of the artificial-ice business is growing at a rapid rate, due in part to distrust of ice from the Hudson and other polluted sources, such has been the growth in the demand for ice that the market for this contaminated product remains undisturbed. It can not, however, remain indefinitely firm, and when the facts have been placed before the public with sufficient intensity the value of the Hudson as a source of ice will be materially damaged. Reference to the report of Prof. William P. Mason made to the Manufacturers' Association of Brooklyn will show very clearly the character of Hudson ice. He substantiates the belief that the formation of ice eliminates impurities to a certain extent, but found upon testing samples of ice taken from germ-polluted fields in the Hudson River, just below the junction of the Mohawk River, that certain disease germs were still alive, and condemned this ice as wholly unfit for use in cooling beverages. Typhoid germs were not killed, as was proved scientifically. He cited the case of a typhoid epidemic which spread from Schenectady to Albany, the Mohawk River carrying the typhoid germs down to its mouth, polluting the ice formed in the Mohawk, whence the ice supply of both cities was obtained. In this manner both cities suffered with a typhoid epidemic.

The association is to present petitions to both the State and city health boards, asking that some steps be taken to prevent the polluted ice being sold in this market.[a]

The above declaration from so distinguished an authority can not be barren of results, and the consequent action taken by the Manufacturers' Association can not fail to be adverse to the use of ice cut on the Hudson. It will produce no widespread revulsion, nor will the ice industry of the river be destroyed in a season, but there can not fail to be a gradual concurrence in the idea that Hudson River ice

[a] Abstract in Municipal Journal and Engineer.

is an inferior article, the price of which will be forced lower and lower by the active commercial spirit of this country. It will not be necessary even to advance hygienic considerations beyond the point at which they are able to beget distrust in the market of New York.

According to prevailing prices, the last Hudson ice crop is worth at least $8,000,000. In unfavorable seasons the pure article from that source could not fall below an annual value of $3,000,000. For what fraction of this sum annually could all the Hudson Basin sewage be purified?

WATER SUPPLY.

The estimation of loss of capital in a river which is polluted to the degree apparent in the Hudson can not be brought to a very fine point of accuracy. If we were to consider the effect of sedimentation, and figure out all the other factors that are effectual in the so-called self-purification of rivers; if we were to consider the amount and character of the sewage and the dilution thereof, we might be able to reach an approximate figure of damage, and even then it would be of little more value than the rough résumé that can easily be made. If the science of water purification were in the same state in which it was a quarter century ago the problem would be more simple, for at that time there were no well-established, reliable means of purification in common use in this country. To-day, however, the purification of polluted water for domestic use has reached that state of perfection at which it has become the practice of reputable engineers to take polluted water from a stream at the very doors of the city and purify it, rather than to expend large sums of money in conserving an unpolluted supply miles away in a sparsely settled district. The case of Philadelphia at the present time is pertinent: On January 4, 1901, the United States Senate Committee on the District of Columbia convened at New York to discuss with the engineering profession the question of filtration of water supply at Washington, D. C. Mr. Rudolph Hering, M. Am. Soc. C. E., stated in his testimony with reference to the experience of Philadelphia that, in 1883, he was engaged by that city to make studies for the new city water supply. As the subject of water filtration was not fully developed at that time he recommended an unfiltered water, taken from the Blue Ridge. More recently, during his connection with the Philadelphia waterworks, he recommended the Schuylkill River and the Delaware, because of the fact that this water could now be made sufficiently pure for use, and under the circumstances it presented a more feasible plan from every standpoint, for both present and future generations.

It becomes necessary then, in considering pollution in a river from the standpoint of water supply, to make allowance for the fact that the water can be purified and that its precedent pollution does not constitute a complete loss of resource. Under such circumstances

the actual amount of damage done consists of the difference between the cost of pumping raw water for direct use and the cost and maintenance of a filtration system.

There remain certain rivers, the pollution of which seems altogether unnecessary, which could be preserved in approximately their normal state, yet which receive sewage enough to damage their water supply values. Such streams are the Wallkill and Batten Kill. In such instances, where the cost of sewage disposal would be comparatively small, there seem to be no compensating factors to offset the damage done to the river as a source of water supply, and pollution becomes needless and unwarranted.

The cities on Hudson River proper that now derive all or a part of their water supply from the river by pumping are Poughkeepsie, Catskill, Hudson, Albany, Rensselaer, and Troy, including the recently annexed Lansingburg. In all of these places except the latter the water is filtered, and in the latter case only a part of the supply is derived from the Hudson.

The filtration systems at Poughkeepsie, Catskill, and Hudson were established before the present knowledge concerning the action of filters was very clearly defined, and there was no idea of purification of the water in the sense that that term is now understood by the profession. The main object of these filters was that of clarification, i. e., an elimination of the sediment which is carried down the Hudson in large quantities, and if there had been clear water in the river the chances are that neither of these filters would have been installed at that time. The cost of construction in these three cases can not, therefore, be charged against the debt of sewage pollution. Whatever may have been the initial cause of installing the Poughkeepsie, Hudson, and Catskill filters, it is apparent that they are at present maintained for the added purpose of biological purification as well as that of clarification. It would be quite unlikely that, should the waters of the Hudson become free from sediment, the filtration system would be abandoned in the face of all the sewage coming past their respective intakes, so that it is a fair position to assume that pollution is partially responsible for the expense of maintenance of these filters. While this section of the Hudson is under consideration it may be of value to pursue this subject with the help of a projected enterprise that emphasizes in a forcible manner the damage that must be faced in such rivers.

One of the most thoroughly discussed water-supply problems that has been before the public for many years is that of the present and future supply of the city of New York. In August, 1899, Mr. William Dalton, commissioner of water supply for the city of New York, startled the city and convulsed the engineering profession by recommending that the board of public improvements approve a forty-year contract with the Ramapo Water Company, under which the city

was bound to buy at least 200,000,000 gallons of water daily at a cost of $70 per million gallons. The excessive cost of the water was only one item of disadvantage to which the city was to be subjected by the execution of the contract. The immediate opposition which was developed, headed by Comptroller Bird S. Coler, caused a stay in the proceedings, during which time the matter was investigated by the comptroller and independently by the Merchants' Association of New York, a body whose power in city affairs and in the establishment of sound corporate policy has ever been notable. An organized staff was made up from the association and, aided by the comptroller and Governor Roosevelt, every phase of the proposed swindle was laid bare. In addition to this, investigations were made into every branch of the water-supply question, and the report that was issued is one of the most valuable of the recent publications on this subject. The engineering committee, under the leadership of Mr. Rudolph Hering, instituted among other things an investigation into the available sources of supply for the city and, with their consulting engineer, Mr. James H. Fuertes, carefully considered every adequate source of supply in the State, finally deciding that the most feasible plan was the pumping of the water from the Hudson River itself, at a point just above the city of Poughkeepsie, where a supply of 1,500,000,000 gallons daily was easily available if proper compensating reservoirs were constructed in the Adirondacks for replenishing the river during dry seasons.

It is the consideration of this extensive project and the analysis of the estimates of cost and maintenance thereof that give the inquirer his first adequate idea of the loss which may arise and the damage which may accrue to the resources of the Hudson River through pollution. These estimates were based upon a proposed supply of 500,000,000 gallons daily, which is probably the maximum additional supply that will be required by the city during a long term of years. The minimum cost for such a system would be $72,374,000, of which $32,557,000 is for filters and pumping plant, largely made necessary by sewage pollution. The minimum cost for the water at this rate would be $30.39 per million gallons, of which $4, or about 13 per cent, is the amount expended for filtration. In the estimated annual cost of operation and maintenance is included $730,000 for cost of filtration. If in the course of years it should become neeessary to develop such a system to its full capacity the cost of overcoming the effects of sewage pollution would increase accordingly. Thus it may be seen that if at any time in the future the city of New York should adopt the Hudson supply and use the maximum amount, the polluted condition of the river would necessitate an annual expenditure of at least $2,000,000 in addition to the initial cost of establishing so gigantic a filtration system.

The history of the Albany water supply is closely linked with the

history of pollution in the Hudson at that point, and the recent establishment there of what was, at the time of construction, the largest filter in the country is a direct consequence of the sewage in the river from the Albany sewers as well as from the numerous places within a short distance above. In the year 1873 it became necessary to augment the gravity system of water supply then in use at Albany, and an intake was placed in the Hudson and water was pumped therefrom into the reservoirs, to be mixed with the upland water. With the growth of the city more and more was pumped from the Hudson, until at the present time the pumped water exceeds in amount that taken from the old gravity system. Throughout the history of its water system Albany has employed eminent authorities to guide her steps, and the establishment of this Hudson intake appears to have been undertaken advisedly. When, after the lapse of some years, there arose a feeling that all was not well with the water, fears were again quieted by the reassurances of a distinguished gentleman. Whatever deleterious material might be poured in the river at Troy, 4 miles above the intake, would be, said the expert, rendered entirely harmless through various influences, among which were sedimentation, dilution, and oxidation. The fact that the death rate and morbidity from typhoid fever was high seemed to have no bearing upon the case, nor was there, in the opinion of the city's advisers, any significance in the fact that epidemics at Albany followed those at Troy, Schenectady, and other places. The eminent authority maintained his position and, we believe, sticks to his conclusions to-day.

In 1885 Prof. William P. Mason, in a report to the water board, showed very clearly the deplorable condition of the water and condemned it in unmistakable terms. From that time until 1896 there was a series of efforts to provide a new supply, all of which failed, until in July, 1897, it was finally decided to filter the water from the Hudson. Under the direction of Mr. Allen Hazen, M. Am. Soc. C. E., a covered filter was constructed at a cost of about $500,000, and the expense of operation is about $4.19 per million gallons, or about $20,000 annually. The results have already been more than sufficient to pay for the cost of the construction. The death rate from typhoid fever has been very materially decreased, and the good effects of the filtration system remain undisputed.

Troy up to the present day is drawing a part of its water from the Hudson and delivering it to its citizens in the raw state, and for years efforts have been made to obtain a new supply, until there seems now to be an assurance of better water. This city has been even slower than Albany to realize the damaging effects of Hudson water, and the indifference of the citizens there has called from Prof. William P. Mason the statement, made during his testimony before the Senate Committee on the District of Columbia, that "up in Troy anything short of soup would be satisfactory." The new water supply, which the bet-

ter element in Troy has at last succeeded in pushing to a successful issue, is to be conserved in sparsely settled districts east of the city. It will furnish, when fully developed, about 40,000,000 gallons daily, and the present plans contemplate an expenditure of $1,250,000.

These are the actual water-supply expenditures which have been made necessary by sewage pollution in the main river and also the costs which would be incurred should the plan recommended by the Merchants' Association for the future supply of the city of New York be adopted. It is clear that the Hudson River along this section must necessarily be polluted, and the expense of water filtration must always be regarded as one of the running expenses to be perpetually maintained in the Hudson Valley. There is no possible way of overcoming it, and it must be considered in a summary of this character. It may be contended that the free drainage of cities into the Hudson is a privilege which compensates for the disadvantages that arise from the damage to the natural water resources. A little reflection will show that such a contention is idle, and that, after allowing for all the items which constitute the credit side of the present account, we shall find that the pollution of the Hudson River is very costly.

The eastern tributaries of the Hudson are not damaged to any great extent by pollution, except the Hoosic and Batten Kill. At the present time the water from the former river is badly contaminated, yet not sufficiently to damage any of the resources which it has, up to this time, been called upon to yield. The ice industry upon the river is not worth considering, and the only resource which is damaged is the water supply. If there should ever be a demand for the water in the basin of the Hoosic it would be necessary to resort to filtration under the present conditions. Pollution in the Hoosic is positively needless, and its existence there is damaging to a resource which, properly cared for, would be one of the fairest in the Hudson River basin. The same statements are true with reference to Batten Kill. Although the contamination of this stream is less than that of the Hoosic, there is sufficient to cripple its usefulness as far as the use of its raw water is concerned.

Similar statements may be made concerning the western tributaries. The Wallkill is a river which seems excellently adapted for water supply, and if proper care were exercised it might be possible for each municipality along its banks to establish its water intake at almost any convenient point along the river and use the water with safety.

There is little to add concerning the Mohawk. We have seen that it is the river which contains the greatest relative amount of pollution of all those tributary to the Hudson, and that the sewered population along its banks numbers 152,000. The only cities which have of late attempted to draw their supplies from the Mohawk are Rome, Schenectady, and Cohoes. Above the first mentioned city the water is fairly satisfactory from a sanitary standpoint, but at Schenectady

LOG JAM IN ADIRONDACK BROOK, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

the work of Dr. Theobald Smith was too conclusive to admit of any doubt concerning the dangerous quality of the water. Consequently that city has been obliged to abandon its intakes in the river and is now supplied by driven wells. Cohoes is still contented to drink from the cesspool of its neighbors.

It would, no doubt, be impossible to make the Mohawk pure. If all sewage pollution were eliminated, it is probable that the surface drainage of so populous a country would unfit the water for use in its raw state as a domestic supply. Certainly, if such is not the case at present it will be true within a few years. The present danger is that the conditions along the Mohawk may approach those of the Passaic; it will be remembered that the increase of population here is greater than at any point that we have considered in the Hudson drainage area.

The water-supply damages cited on the Mohawk, then, are total unfitness of the stream as a source of raw supply and necessary abandonment of an intake by the city of Schenectady.

The character of Saratoga Lake, and the use to which it has been put, makes its use as a water supply undesirable. It might, of course, have been used for this purpose before it became so polluted, but, as it is a part of the great summer resort, it is natural, and almost imperative, that it should be given up to recreative purposes and as such it becomes unimportant from the standpoint of water supply.

REALTY VALUES.

There are many places in the Hudson drainage area that have been made undesirable by sewage pollution, but in the majority of cases they are so very close to sewer outlets that nothing else could be expected, and the surrounding neighborhoods have been adapted to meet such conditions. Such places must ever exist—it is necessary for every city to have its garbage area and dust bin, and it has become the custom to develop these surroundings in such a way that the interests involved do not suffer materially by the existence of that which, in residential districts, would seriously impair established values. There is no place on the Hudson where the condition approaches that upon certain parts of the Passaic, where land has been reduced to no value and localities have been brought to a standstill. The region about Johnstown on Cayudutta Creek and the shores of Saratoga Lake have been fast approaching that condition, but up to the present time there has been only a relatively small amount of realty damage.

The law reports of New York State contain, here and there, cases arising out of polluted conditions in this area, the most important of which are the following:

Supreme court, May term, 1891 (67 Hun, p. 294); Joshua Demby *v.* City of Kingston, N. Y.:

The plaintiff and wife were tenants by entirety upon two lots, through

which ran a stream that was polluted by city sewers. Plaintiff was obliged to cover stream and to incur considerable expense to get rid of nuisance, and finally sued the city for damages and prayed for an injunction against further pollution.

The city held that it was not responsible, as the nuisance was caused by private connections in a sewer built for storm water, and the city could not go upon private property and remove them. The award of the jury in the lower court was affirmed, the amount being $524, and a permanent injunction was issued.

Supreme court, September term, 1893 (71 Hun, p. 232); Simon Schriver *v.* Village of Johnstown:

The case was presented on appeal from the lower court, in which the jury awarded $2,000 damages, and the court issued a permanent injunction. A part of the opinion of the supreme court is as follows:

The maintenance by a municipality of a permanent system of sewers, through which sewage passed into a natural stream and pond of private ownership, causing pollution and sediment, presents a case for perpetual injunction and normal damages. The measure of damages in such a case is the depreciation of rental value.

The estimated rental value of the pond was $600 per annum. Of this $400 was still available under the polluted conditions, leaving a balance of $200 for which the city was responsible. Damage for ten years, amounting to $2,000, was affirmed, and the permanent injunction was continued.

Supreme court, appellate division, May term, 1897 (17 New York, p. 207); Moody *v.* Saratoga Springs:

An appeal by defendant from verdict in lower court in favor of plaintiff. Damages were awarded and an injunction was issued.

The principal contention before the court of appeals was that the village was not responsible by reason of the act of the legislature which authorized the construction.

A part of the opinion rendered by the higher court reads:

The purpose of chapter 149 of Laws of 1885, providing for the extension of the main sewers of Saratoga Springs, was to promote the interests of the village, and the village is liable to the owner of premises near a creek into which said extension is discharged from the injuries resulting from the pollution of air and water caused by such discharge.

An act which authorizes the extension of a sewer authorizes its use, but such use must not result in a nuisance or occasion injury to the legal rights of others.

In conclusion, having considered as minutely as seems advisable the different sources of pollution in the Hudson River basin, and having indicated in a brief, summary manner its effect upon the natural water resources, it now remains to determine what may be the future of these resources and whether pollution will continue to grow or be checked by popular disapproval and consequent legislative enactment.

The whole question has been modified by the successful introduction of filtration for water supplies. It is manifest that the most potent damage that is ordinarily done to the resources of a stream is its destruction for use as a source of water supply, but, having overcome this difficulty by the introduction of filters, it is more than likely that the tendency will be toward toleration of a certain amount of pollution, and the expense of filtration will be regarded as a fixed charge upon the community at large.

The growing use of sewage purification processes has also a bearing upon the pollution question. The effluent from sewage purification works, while properly and theoretically harmless, can not at all times be depended upon to thoroughly eliminate all the pathogenic bacteria that are found in it. There must be laxities, arising in even the most carefully conducted sewage purification plants, that are entirely unavoidable. Sewage will pass through the purification process and will not be treated so efficiently as the process of purification will permit nor so carefully as the diligence of those in charge would seem to warrant. Under such circumstances it is clear that we can not place sufficient dependence upon sewage purification to warrant us in using for potable purposes the raw water from a river into which such effluent is emptied.

Natural surface drainage, too, is to be considered. Upon rivers having large cities along their shores a certain amount of pollution must arise from the natural drainage of occupied land, and this may be a detriment to the river. Such contamination is unavoidable, and is certainly not so important as that from city sewers, yet it is true that the uncertainties that arise make it necessary to avoid the use of water so contaminated for domestic purposes without filtration. So it appears, as already observed, that the tendency will be to assume that the contamination incident to the surface drainage of occupied land and the effluent from sewage purification works is a necessary and unavoidable evil, and to consider that the diminution of natural water resources by this means is one of the prices which society must pay for its social and economic development.

The above applies to rivers with considerable population in their immediate drainage areas. The pollution of upland streams in sparsely settled districts must, however, be regarded as needless, and as a crime against the community. The greater part of these areas possesses little value from an agricultural standpoint. Under the present conditions they are principally useful in raising forests. The highest development of their natural values would arise by setting them aside as regions for the conservance of water. In this way the forestry and water problems could be dealt with coincidently, and the adoption of such as a public policy would be wise.

The damage to ice interests by sewage pollution will, in the course of years, settle itself. The manufacture of ice is a growing industry,

and when the time shall come that polluted ice is no longer tolerated, the use of artificial ice will become universal. The rivers that are now used as ice fields are, in the majority of cases, those that are polluted to a greater or less extent, so that the damage to that part of the water resources must also be assumed in the same spirit as that just described with reference to water supplies. It will, in this case, be a surrendering of certain natural sources of wealth for an equal value in a new industry.

Within the area covered by this brief analysis there are a few interstate features, although the questions involved are not now of local interest. We have seen that a part of the drainage area of the Passaic extends over into the State of New York and that the Hudson River Basin comprises small parts of Vermont, Massachusetts, and New Jersey. What the future may bring forth in these places with regard to interstate pollution is a matter of conjecture, yet if the cities of North Adams, Mass., and Bennington, Vt., should grow sufficiently to pollute the Hoosic River to the same extent that the Passaic or Cayadutta Creek is now polluted, there would arise damages to different interests in the State of New York which the courts of that State could not correct. What the result would be is uncertain, for there is not yet any well-defined process nor any established practice by which such matters could be easily adjusted. There is a national authority over common interstate matters, and there should be an equal control over the interstate features of rivers whose courses lie within two or more States.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 12, 1902.

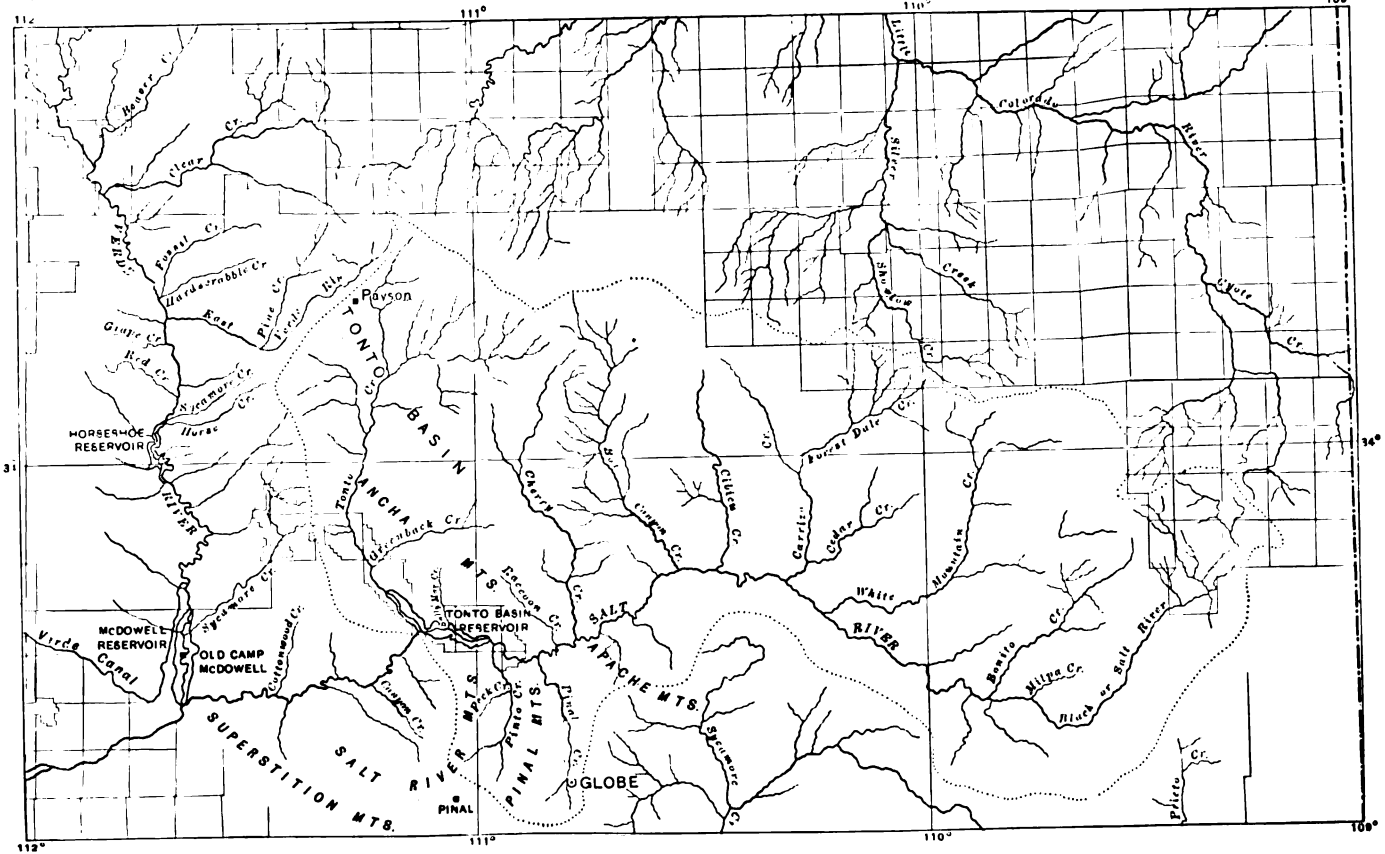
SIR: I have the honor to transmit herewith a manuscript by Mr. Arthur P. Davis, giving the results of surveys and investigations for water storage on Salt and Verde rivers, Arizona, and request that it be published in the series of Water-Supply and Irrigation Papers.

The results described in this report were obtained by Mr. Davis mainly during the year 1901. Assistance was rendered by the local authorities, committees, and citizens of Maricopa County, Ariz., and through the cooperation thus had it was possible to go into details which under other circumstances could not have been discussed. The work is of great value, not only to the Salt River Valley, but to other portions of the arid region where water storage will in the future be undertaken, as the careful work of Mr. Davis has demonstrated the feasibility of utilizing natural resources, particularly in the making of cement and turning to advantage previously unsuspected means for conserving water. Throughout Arizona and the entire Southwest the development of agriculture, and to a less extent of mining and other industries, rests upon water conservation, since in these vast areas the streams are for the most part of small volume and are subject to occasional destructive floods. The impounding of these is one of the most important fundamental steps to be taken toward the utilization of the vast area of vacant public land.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



DRAINAGE LINES OF SALT RIVER BASIN

WATER STORAGE ON SALT RIVER, ARIZONA.

By ARTHUR P. DAVIS.

INTRODUCTION.

Salt River Valley lies south of the center of the Territory of Arizona, and contains by far the largest irrigated area in that Territory. Its water supply is obtained from Salt River, forming below the confluence of Verde River the largest stream in Arizona.

Verde River drains the central portion of Arizona, and Upper Salt River the east central portion. Both streams are more or less torrential in character, the combined flow dwindling at times to about 100 cubic feet per second, and at other times reaching a volume more than one hundred times as great.

The development of Salt River Valley has been carried on by diverting the natural flow of the river, which is not sufficient for the adjacent lands. Settlement and cultivation, encouraged by years of large or normal water supply, have reached a point where dryer years do not furnish sufficient water for the proper irrigation of lands already in cultivation, and unless the water supply can in some way be increased not only must agricultural development entirely cease, but some of the land already in cultivation must be abandoned.

The unprecedented drought of the last three years has brought the people of this region to a most vivid realization of this condition, and to a strong determination to by some means secure the construction of reservoirs for the storage of the waters which now go to waste during the melting of the snows in the spring, and during the torrential rains of the late summer. The agitation for storage led to the formation of the citizens' committee in Phoenix for promoting investigations and for developing some project for the storage of water. The action taken is set forth in the following communication received in November, 1900, by the Secretary of the Interior, from Mr. B. A. Fowler, president of the Salt River Valley water-storage committee:

> The citizens of the Salt River Valley of Arizona have, as a result of a protracted drought, become thoroughly aroused to the vital importance of forest protection, and especially of water conservation through the construction of reservoirs. Mass meetings have been held and an organization formed representing all of the diverse interests of the valley. As president of this organization, I have been instructed and empowered to take active steps toward bringing about better conditions.

A careful study of the situation has shown that, as preliminary to the construction of systems of water storage, we must have a full knowledge of all of the physical conditions of topography, water flow, depth of bed rock, amount of sediment carried by the water, and other facts. With these fundamental facts, and with estimates of the capacity and cost of construction, it will be possible to discuss alternative projects, and to lay before the people the data by which they can be guided in future action, and by which Congress may consider the advisability of public works for the regulation of the streams and for the reclamation of arid lands.

We understand that one of the bureaus of the Department of the Interior, viz, the United States Geological Survey, has been authorized by Congress to ascertain these facts relating to the reclamation of the arid region, the storage of water, and related subjects. Also that the demand for work of this kind far exceeds the funds available for carrying it on, and that as a consequence work is being concentrated in localities where the greatest public interests are to be served, and particularly where cooperation is offered by the people or their legislatures.

In view of these conditions, I am authorized to bring before you the great importance of this work to the people of Arizona, and as an evidence of our earnestness in the matter to offer to cooperate to the extent of furnishing $1,500, to be disbursed upon the usual approved vouchers, an equal amount to be allotted from the funds of the United States Geological Survey, to be expended by the latter in making these investigations. My conference with the officials of the Geological Survey has shown that this proposition is acceptable to them, being similar to the cooperation now in force with the Water and Forest Association of California, and also with officials in various States.

I trust that this matter will meet your hearty approval and this greatly needed investigation can be begun at once.

This letter was referred to the Director of the Geological Survey, who replied to the Secretary of the Interior on January 14, 1901, as follows:

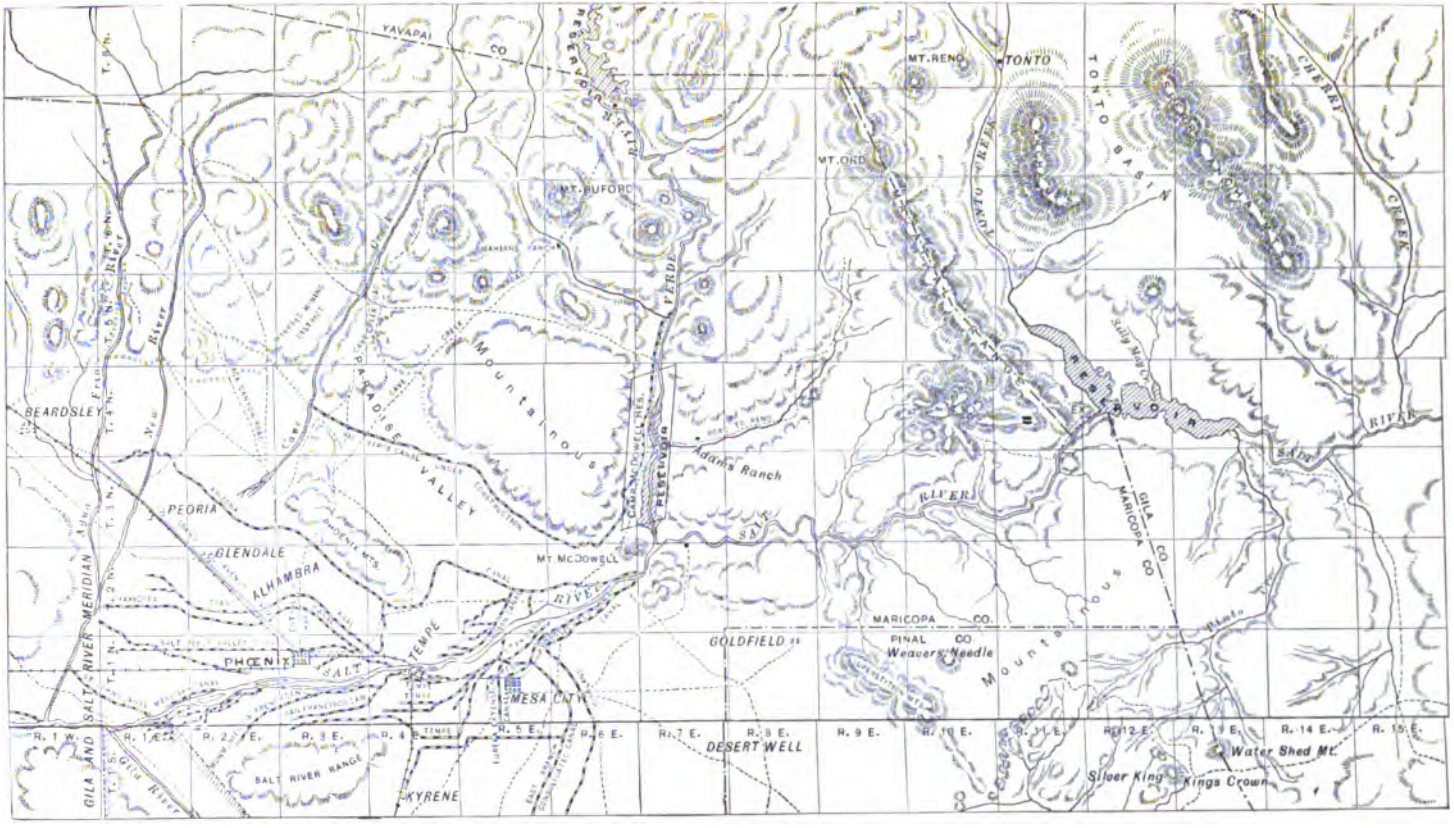
I have the honor to acknowledge, by reference from the Department of December 31, for early report and return of the papers, a letter dated November 20, from Mr. B. A. Fowler, president of the Salt River Valley storage committee.

In this Mr. Fowler offers to cooperate to the extent of furnishing $1,500 in the investigation of the water resources of the portion of country above the Salt River Valley. This offer of cooperation should, in my opinion, be met with hearty approval and investigations pushed forward energetically in those regions where the people testify to the need of this work by furnishing financial aid.

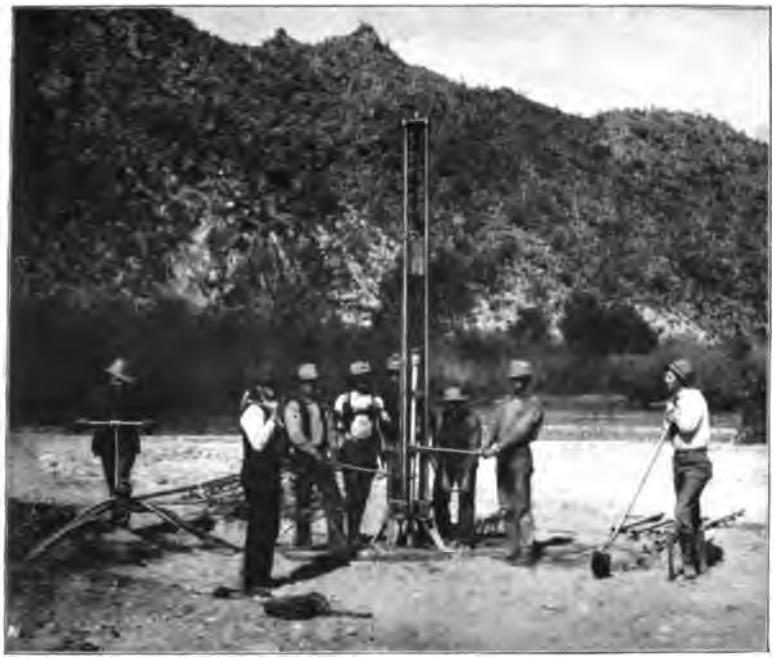
The offer of the Arizona people is comparable to that of the California Water and Forestry Association, which has paid one-half of the field expenses of similar investigations in California during the past year.

Mr. Fowler, after presenting his letter of November 20 to you, and having a personal conversation, filed in this office a copy of the letter. In view of the necessity of beginning work immediately, while the climatic conditions are favorable, I authorized the beginning of this Arizona work, and will have it pushed forward to completion if it continues to meet your approbation, as I understand informally that it does.

The work now in hand consists of a thorough examination of the drainage basin of Verde River, the gaging of the streams, and the determining of the water supply; this latter involving the survey and examination of possible reservoir sites. After this is completed, it is possible that work will be continued on the Salt River above the Verde.



MAP OF SALT RIVER BASIN, SHOWING RESERVOIR SITES.



A DRILL PARTY ON VERDE RIVER; "PIERCE RIG"

B DRILL PARTY ON VERDE RIVER; DIAMOND DRILL.

Accordingly, early in January the investigation of the McDowell reservoir site, near the mouth of Verde River, was begun. Measurements of the flow of the river were also begun at once, and borings were made in order to ascertain the nature of the foundation for the proposed dam. While the borings were in progress surveys were carried on to determine the capacity of the reservoir and the cubical contents of the dam. The work at the McDowell dam site was concluded on April 20, when the public funds available for the work were almost exhausted. About this time the water-storage commission was appointed, under the act of the Arizona legislature, as follows:

No. 65.

AN ACT to authorize any county in the Territory of Arizona having an assessed valuation of eight million dollars or over to prepare plans and specifications for a storage reservoir or reservoirs, dam or dams, to acquire the site for the same, and to provide the necessary funds to defray the expenses incurred.

Be it enacted by the legislative assembly of the Territory of Arizona:

SECTION 1. Any county in the Territory of Arizona having an assessed valuation of eight million dollars or over may avail itself of the benefits of this act by complying with the provisions as hereinafter provided. The board of supervisors, upon the petition of fifty qualified electors and freeholders of said county, shall request the district judge in which the county is located to appoint a board of water-storage commissioners, and the judge shall within ten days thereafter appoint five qualified electors, who shall be resident freeholders of said county, who shall be known and designated as the board of water-storage commissioners. Each of said commissioners shall hold office for one year and until his successor is appointed and qualified. Before entering upon the duties of his office he shall give bond in the sum of one thousand dollars, payable to the said county, for the faithful performance of his duty. Said bonds shall be approved by and filed with the board of supervisors of said county. At its first meeting the board shall organize by the election of one of its members as president. It shall also elect a secretary, who may or may not be of its number. The compensation for the members of said board shall be five dollars per day for each day actually employed. They shall also be allowed their actual traveling expenses. The salary of the secretary shall be fixed by the board. The board shall establish and maintain an office at the county seat of the said county. It shall be the duty of said water-storage commissioners to examine reservoir sites, cause to be made surveys and soundings, determine the capacity and estimate the cost of construction of said proposed reservoir or reservoirs, dam or dams, determine the extent of the watersheds and rainfall thereon; to collect such other information as shall show the water available for storage use in said county for irrigating purposes; to provide for the accumulation of such other information as may be required therefor, and cause abstracts therefrom to be published in some newspaper published and of general circulation in said county; to employ and fix the compensation of a competent engineer or engineers; to prepare plans, specifications, and estimates for said reservoirs and dams and file a copy of the same with the clerk of the board of supervisors of said county; to employ and fix the compensation of legal counsel in any matters arising under this act, or necessary to authorize the construction of the dams or reservoirs referred to in this act, and to select the most available reservoir site or sites, and to acquire the same, together with any rights of way necessary over public or private property, by purchase or through eminent domain, in the name of said county of Maricopa, and for the benefit of the people of said

county; and to negotiate with and obtain agreements from canal companies in relation to the distribution of water or its delivery to the point of ultimate use, and to cooperate with or contribute towards the expenses of any investigations now being made or hereafter to be made by the United States Geological Survey, and to transfer to the National Government any reservoir site or rights therein or thereto, or connected therewith, which may have been acquired hereunder, in the event that the National Government should undertake the construction of the reservoir.

SEC. 2. For the purpose of defraying the expenses of the board of water-storage commissioners, the board of supervisors of any county availing itself of this act shall at the time of levying Territorial and county taxes in the years 1901 and 1902 levy an additional tax of one and one-half mills on the dollar on all taxable property within the said county, to be collected as other taxes are collected; and the same shall be denominated and known as a water-storage fund. The board of water-storage commissioners shall audit and approve all bills for expenses incurred under the provisions of this act, and present the same, together with the claims for their salaries and expenses, to the board of supervisors, who shall, if found correct, pay the same out of any money in the water-storage fund.

SEC. 3. All acts and parts of acts in conflict with the provisions of this act are hereby repealed.

SEC. 4. This act shall take effect and be in force from and after its passage.

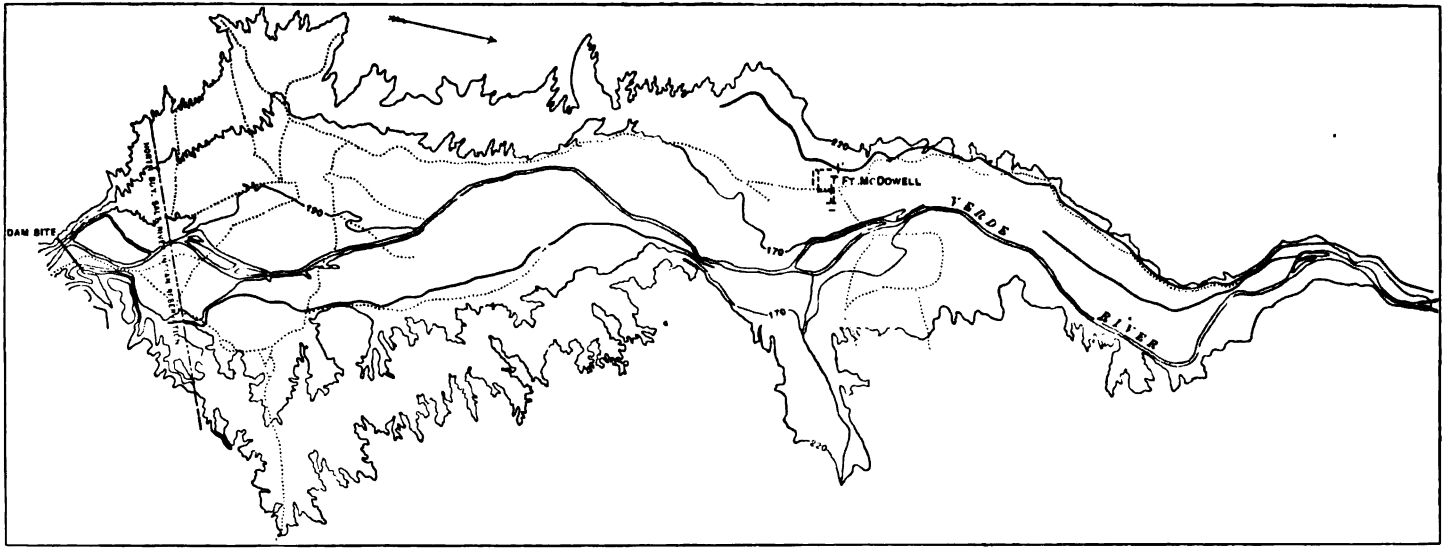
Approved, March 20, 1901.

The water-storage commission consisted of J. T. Priest, Charles Goldman, W. D. Fulwiler, Dwight B. Heard, and J. G. Peterson. Arrangements were made by which the officers of the Geological Survey were to prosecute investigations at the reservoir site on Salt River at the mouth of Tonto Creek, with the machinery and camp equipment of the Geological Survey, the water-storage commission to furnish subsistence and to pay the laborers and incidental camp expenses. Borings and surveys were carried on for about three months, resulting in a thorough knowledge of the foundation conditions for a high dam, the cubical contents of the same, and the capacity of the reservoir site for each 10 feet of elevation above the river from 10 to 200 feet. The results of all these investigations and the plans founded thereon are given in the following pages.

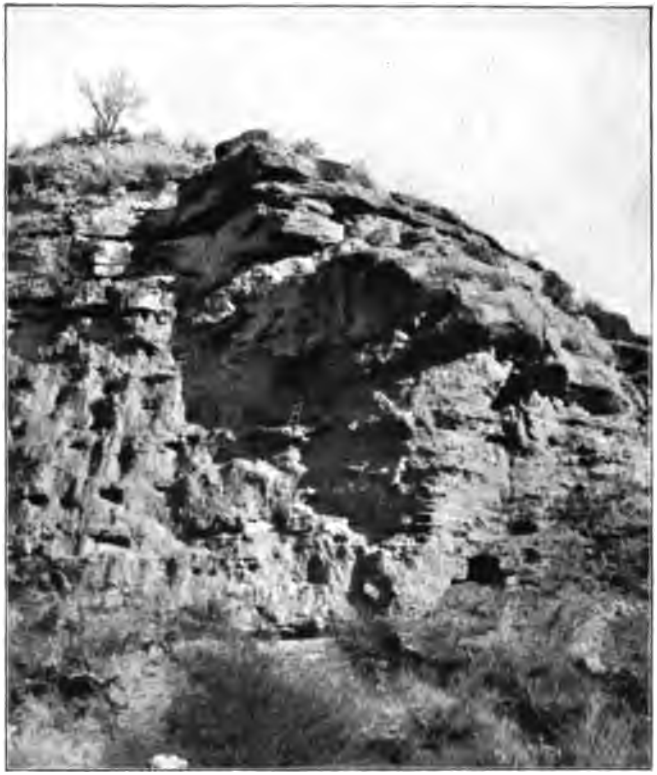
WATER STORAGE ON VERDE RIVER.

CHARACTER OF DRAINAGE BASIN.

Verde River rises in the Black Forest, near the line of the Atchison, Topeka, and Santa Fe Railway. Its general course is a little east of south, draining the Black Hills and Black Mesa. The principal tributaries from the east are Dragoon Fork, Oak Creek, Beaver Creek, Clear Creek, and East Verde River. All are of considerable length and come from mountainous country, with relatively high rainfall, and furnish the main portion of its waters. The only tributaries of consequence from the west are Walnut Creek, near the head, and Granite Creek, which rises near Prescott and flows northward. These creeks are usually dry. The total area drained by the Verde is about 6,000 square miles, ranging in altitude from 1,250 feet at Camp McDowell to over 8,000 feet. The topography of the basin is widely varied in character.



OUTLINE OF McDOWELL RESERVOIR SITE.



CONGLOMERATE CLIFF, McDOWELL RESERVOIR SITE, SHOWING WIND EROSION.

Near the headwaters are Big Chino, Williamson, Little Chino, and Lonesome valleys, each of which is an extensive plain yielding little run-off to the river. The greater portion of the basin, however, is of a mountainous character, being cut with profound canyons and dotted by rugged mountains. Only a small proportion is wooded and the soil is kept nearly bare by excessive grazing. As might be expected, the run-off is largely torrential in character, and the floods carry some silt. In this respect it is not as favorable for storage as the basin of the Salt.

WATER SUPPLY.

The flow of Verde River at Mount McDowell was directly observed by the Hudson Reservoir Company from February 4, 1895, to July 31, 1896; and by the Geological Survey from April 20, 1897, to November 30, 1899, and during 1901. The balance of the record from August 1, 1888, to January 1, 1901, is derived from the record of the discharge of Salt River at Arizona dam below the mouth of the Verde, according to principles set forth on page 24. As these records are necessary in connection with the study of the duty of Salt River reservoir they are given by months in connection therewith, on page 26.

The monthly discharges, as far as completely known, are as follows:

Estimated monthly discharge of Verde River at McDowell.

[Drainage area 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1888.[a]						
August			172	10,547	0.03	0.03
September			168	9,996	.03	.03
October	175	150	166	10,178	.03	.03
November	2,880	213	421	25,050	.07	.078
December	21,745	823	3,349	205,964	.56	.645
The year				261,735		
1889.[a]						
January	10,480	699	2,498	153,611	.42	.48
February	1,773	690	1,172	65,059	.20	.21
March	13,180	1,390	3,411	209,749	.57	.65
April	1,112	499	795	47,302	.09	.10
May	639	118	197	12,141	.03	.03
June	185	107	141	8,390	.02	.02
July	551	140	208	12,819	.04	.04
August	370	191	204	12,556	.03	.03
September	562	187	250	14,880	.04	.04
October	352	160	220	13,530	.04	.05
November	315	266	288	17,136	.04	.04
December	12,686	279	2,843	174,845	.67	.77
The year	13,180	107	1,018	742,028	.18	2.43
1890.[a]						
January	6,615	578	2,092	128,685	.35	.40
February	64,480	470	4,544	252,172	.76	.79
March	6,719	1,001	2,504	153,967	.62	.71
April	415	274	368	21,896	.06	.07
May	260	120	174	10,680	.03	.03
June	202	119	153	9,121	.03	.03
July	366	167	220	13,535	.04	.04
August	3,760	546	1,904	117,074	.32	.37

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.

Estimated monthly discharge of Verde River at McDowell.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1890.[a]						
September	1,769	348	1,123	66,802	.19	.21
October	3,733	377	1,384	80,116	.02	.02
November	15,252	383	2,359	140,331	.39	.43
December	15,183	555	3,130	192,464	.52	.59
The year	64,480	119	1,666	1,186,843	.278	3.69
1891.[a]						
January	7,193	445	1,435	88,244	.22	.25
February	135,000	371	17,467	970,051	2.91	3.18
March	3,460	525	1,928	118,535	.32	.37
April	606	459	534	31,775	.09	.10
May	361	365	458	28,190	.08	.09
June	539	280	401	23,849	.07	.08
July	405	252	314	19,291	.05	.06
August	368	251	278	17,113	.05	.06
September	631	229	395	23,478	.06	.07
October	310	231	258	15,833	.04	.04
November	314	231	256	15,233	.04	.04
December	346	294	328	20,168	.05	.06
The year	135,000	229	2,004	1,371,760	.332	4.35
1892.[a]						
January	360	257	284	17,458	.05	.06
February				[b]11,046		
March				[b]9,832		
April				[b]5,213		
May				[b]5,608		
June				[b]3,106		
July	215	136	152	9,374	.02	.02
August	276	162	198	12,172	.03	.03
September	188	157	164	9,768	.03	.03
October	875	164	223	13,712	.04	.04
November	435	225	257	15,263	.04	.04
December	296	263	282	17,309	.05	.06
The year				129,861		
1893.[a]						
January	231	231	231	14,204	.04	.04
February	4,781	248	672	37,313	.11	.11
March	144,306	230	5,386	331,168	.90	.04
April	495	141	290	17,244	.05	.05
May	380	64	150	9,258	.02	.02
June	106	44	68	4,052	.01	.01
July	478	117	225	13,842	.04	.04
August	1,240	233	802	49,321	.13	.15
September	1,164	284	530	31,532	.09	.10
October	244	276	376	23,120	.06	.07
November	339	280	296	17,613	.05	.06
December	325	313	315	19,338	.05	.06
The year	144,306	44	778	568,000	.13	1.76
1894.[c]						
January	264	231	244	15,030	.04	.04
February	284	236	259	14,395	.04	.05
March	996	205	530	32,565	.09	.10
April	269	95	171	10,187	.02	.02
May	89	60	68	4,159	.01	.01
June	133	66	79	4,713	.01	.01
July	223	66	119	7,334	.02	.02
August	923	140	439	26,996	.07	.08
September	715	139	292	17,365	.05	.06
October	714	122	242	14,880	.04	.04
November	303	207	230	13,656	.04	.04
December	820	233	442	27,147	.07	.08
The year	923	60	259	188,427	.04	.54

[a] Obtained by taking proportional part of discharge of Salt River at Arizona dam.
[b] Approximate, from minimum discharge recorded for same months in 1900.
[c] Obtained by taking proportional part of discharge of Salt River at Arizona dam. Using Mr. Trott's computations.

A. WEST ABUTMENT OF McDOWELL DAM SITE, SHOWING GAGE ROD.

B. EAST ABUTMENT OF McDOWELL DAM SITE.

Estimated monthly discharge of Verde River at McDowell—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1895.[a]						
January	33,000	527	4,067	248,225	.67	.77
February	5,800	583	1,688	93,747	.28	.29
March	8,400	1,887	3,720	228,734	.62	.71
April	2,800	290	750	44,628	.13	.14
May	429	127	258	15,864	.04	.04
June	180	129	153	9,104	.03	.03
July	275	116	145	8,916	.02	.02
August	1,426	185	359	22,074	.06	.07
September	348	141	176	10,473	.03	.03
October	3,912	197	475	29,207	.08	.09
November	1,800	241	463	27,550	.08	.09
December	881	345	391	24,042	.07	.08
The year	33,000	116	1,051	762,564	.18	2.36
1896.						
January	354	314	324	19,923	.05	.06
February	352	278	154	8,852	.03	.03
March	388	258	276	16,971	.05	.06
April	237	206	220	13,090	.04	.04
May	206	138	172	10,576	.03	.03
June	137	101	117	6,962	.02	.02
July	3,380	98	864	53,127	.14	.16
August[b]	5,323	272	849	52,213	.18	.21
September[b]	4,466	252	557	33,132	.06	.07
October[b]	690	301	452	27,823	.05	.06
November[b]	747	334	492	29,306	.05	.06
December[b]	444	326	352	21,644	.04	.05
The year[b]	5,323	98	402	293,629	.06	.85
1897.						
January[b]	15,687	252	2,138	131,474	.36	.41
February[b]	2,245	487	873	48,484	.15	.16
March[b]	4,013	706	1,504	92,492	.25	.29
April[b]	2,706	316	1,189	70,774	.20	.23
May	460	170	269	16,540	.045	.052
June	185	120	150	8,920	.025	.028
July	230	90	130	7,998	.022	.025
August	1,590	110	439	26,998	.073	.084
September	5,000	240	992	59,028	.165	.184
October	390	260	309	19,000	.051	.059
November	265	260	262	15,590	.044	.049
December	280	260	267	16,417	.045	.052
The year	15,687	90	710	513,705	.12	1.61
1898.						
January	1,680	120	253	15,556	.04	.04
February	800	290	496	27,546	.08	.09
March	1,535	210	639	39,291	.11	.13
April	710	180	319	18,982	.05	.06
May	280	130	184	11,314	.03	.03
June	160	130	139	8,271	.02	.02
July	1,890	115	323	19,861	.05	.06
August	1,730	165	400	24,595	.07	.08
September	1,380	165	338	20,112	.06	.07
October	180	160	169	10,391	.03	.03
November	230	165	195	11,603	.03	.03
December	440	220	303	18,631	.05	.06
The year	1,890	115	313	226,153	.05	.70
1899.						
January	560	295	350	21,521	.06	.07
February	375	295	344	19,105	.06	.06
March	325	225	260	15,987	.04	.05
April	230	170	205	12,198	.03	.03
May	210	118	152	9,346	.03	.03
June	230	118	152	9,045	.03	.03
July	1,400	118	365	22,443	.06	.07
August	2,170	100	434	26,686	.07	.08
September	2,500	135	357	21,243	.06	.07
October	3,770	160	549	33,757	.09	.10
November	250	235	203	13,240	.03	.03
December	364	223	292	13,343	.05	.06
The year	3,770	100	305	217,914	.05	.68

[a] Obtained by taking proportional part of discharge of Salt River at Arizona dam. Using Mr. Trott's computations.

[b] Computations made from Mr. Trott's figures.

Estimated monthly discharge of Verde River at McDowell—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.[a]						
January	195	179	189	11,621	.03	.03
February	211	184	199	11,046	.03	.03
March	187	144	160	9,832	.03	.03
April	125	74	88	5,213	.01	.01
May	190	46	91	5,608	.02	.02
June	75	36	52	3,106	.01	.01
July	105	36	52	3,176	.01	.01
August	555	68	151	9,235	.02	.02
September	305	92	121	7,198	.02	.02
October	408	107	183	11,252	.03	.03
November	2,469	163	430	25,617	.07	.08
December	272	205	224	13,775	.04	.04
The year	2,469	36	161	116,679	.025	.33
1901.[b]						
January	1,557	259	351	21,575	.06	.07
February	6,613	394	1,859	103,249	.30	.31
March	2,863	211	895	55,018	.15	.17
April	221	155	184	10,988	.03	.03
May	185	125	139	8,606	.02	.02
June	164	59	104	6,222	.02	.02
July	1,430	29	210	12,916	.04	.04
August	1,755	163	627	38,561	.11	.13
September	172	45	93	5,514	.01	.01
October	495	82	134	8,210	.02	.02
November	336	187	245	14,571	.04	.04
December	291	247	268	16,485	.04	.04
The year	6,613	29	426	301,915	.07	.90
1902.						
January	262	197	224	13,785	.03	.03
February	248	227	239	13,277	.04	.04

[a] No observations made during 1900 by United States Geological Survey. Computations made from Mr. Trott's figures.
[b] Computations made from observations taken by United States Geological Survey.

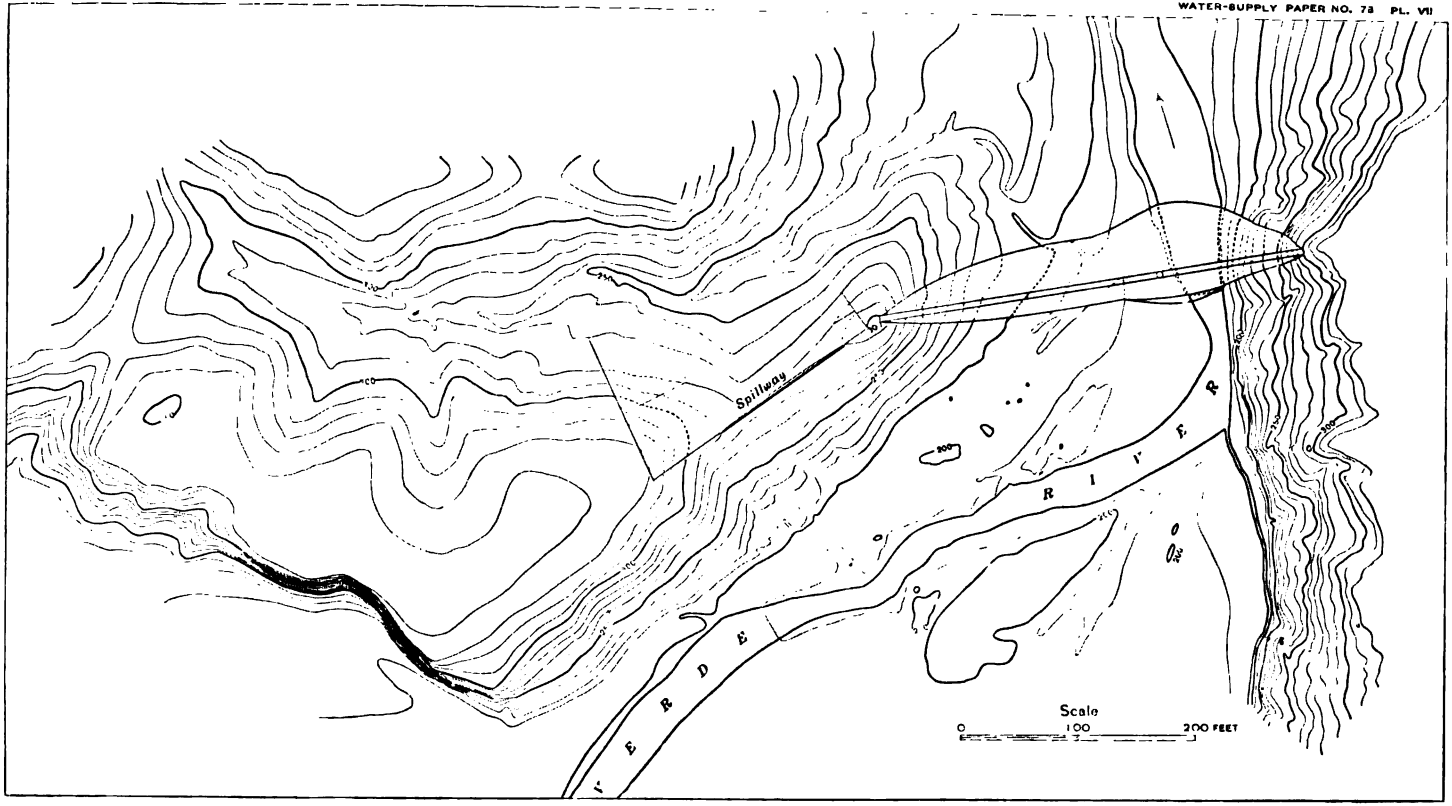
Two storage reservoirs have been proposed upon Verde River. The Horseshoe reservoir, which is described in Water-Supply and Irrigation Paper No. 2, page 62, is situated about 30 miles above old Camp McDowell, near the mouth of Limestone Creek. An outlet tunnel has been cut and a portion of the canal has been built, but work has been suspended for several years. The capacity of this reservoir would be about 200,000 acre-feet.

McDOWELL RESERVOIR.

This reservoir site is situated above Mount McDowell, near the mouth of the Verde, and includes the site of old Camp McDowell. The dam site is about 2 miles above the mouth of the Verde. This reservoir site was suggested and partly surveyed by Mr. Frank P. Trott, the water commissioner of Salt River Valley.

BORINGS.

Early in January, 1901, field work was begun by the Geological Survey, and an examination of the McDowell reservoir site on Verde River was made. Two pipe-driving machines and a diamond drill were taken to the ground, and borings were begun to determine the position and character of bed rock at the site of the proposed dam, Mr. W. E. Jones, of Des Moines, Iowa, being employed as drill foreman.



PLAN OF McDOWELL DAM.

Mr. C. R. Olberg was intrusted with the construction of a map of the reservoir site in 10-foot contours, on a scale of 1,000 feet to an inch, and a detailed map of the dam site was made on a scale of 100 feet to an inch. The field work was under the general direction of Mr. F. P. Trott, whose duties as water commissioner, however, prevented his continued presence on the ground, so that the immediate charge was assigned to Mr. E. G. Hamilton.

The borings began by attempting a straight row of holes along the axis of the dam proposed by Mr. Trott. The conditions were found to be very difficult. At a depth of about 30 feet a bed of very hard cemented gravel was encountered, into which it was impossible to drive the pipe, except with the assistance of blasting, but which was not sufficiently coherent to be classed as solid rock.

The work was also hampered by the fluctuation of the river, the floods threatening several times to wreck or sweep away the machinery.

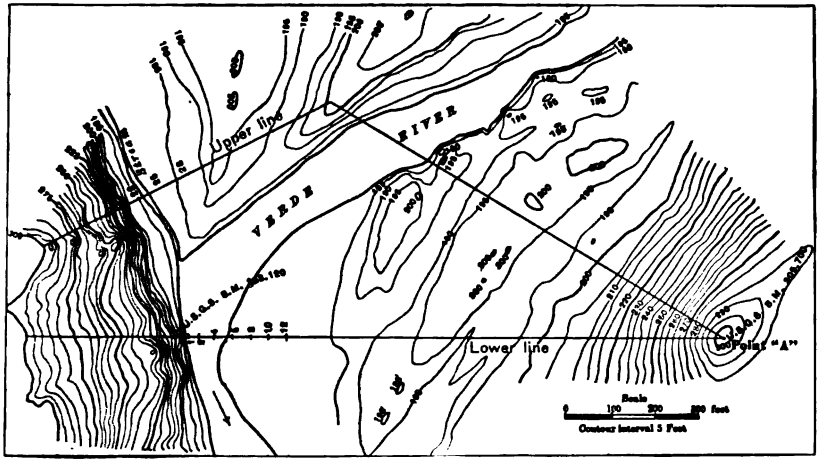


FIG. 1.—Plan of borings at McDowell dam site.

By February 26 it had been demonstrated that it was at least more than 70 feet to bed rock in hole No. 6 on the main axis of the proposed dam, and the work being hampered here by fluctuating water, Mr. Trott determined to try along an alternate location, shown in fig. 1, farther upstream, and both machines were set to work there on holes Nos. 21 and 25. The former was soon completed, showing a depth to rock of 21 feet. The machine was removed to the site of No. 28. Work was pushed on 25 and 28 until the former reached a depth of 90 feet without striking rock. This was considered a prohibitory depth for this location and the machinery was returned to the first location to continue the exploration of the main line. This was completed on April 20.

The location of the borings on both lines is shown in fig. 1. The depths of borings are shown in the table following.

Borings at McDowell dam site.

Hole number.	Distance from bench mark.	Depth to bed rock.	Total depth.	Character of bed rock.
	Feet.	*Feet.*	*Feet.*	
1	20	22	22	Granite.
2	40	35	38	Rotten granite.
4	80	90	99	Broken granite.
6	120	80	92	Do.
8	160	49	59	Granite.
10	200	40	46	Hard gray granite.
12	240	52	65	Broken granite.
21		22	26	Granite.
25			90	No bed rock reached.
28			50	Do.

CAPACITY.

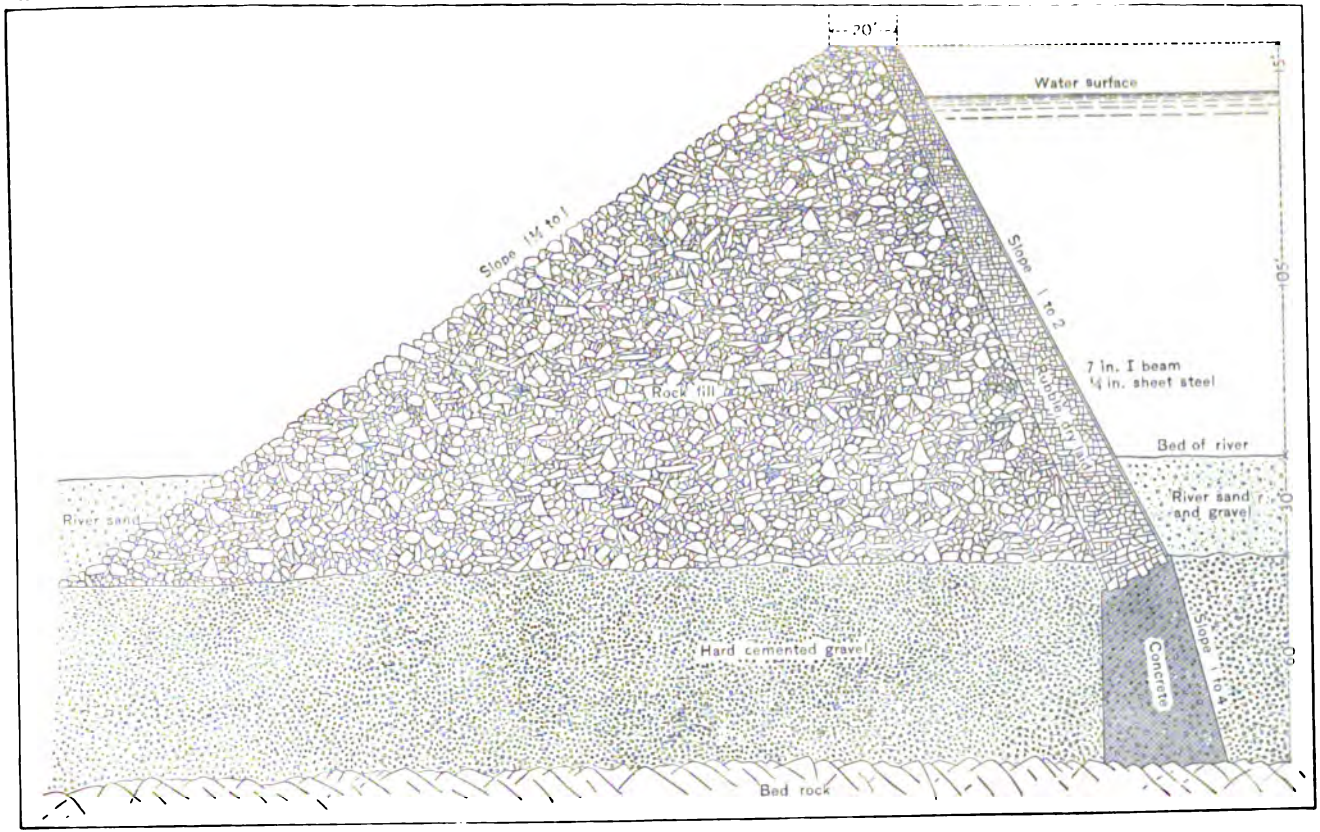
Capacity of McDowell reservoir.

Elevation above lowest foundation.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
100	14	70	70
110	91	525	595
120	331	2,110	2,705
130	717	5,240	7,945
140	1,073	8,950	16,895
150	1,661	13,670	30,565
160	2,292	19,765	50,330
170	3,134	27,130	77,460
180	4,034	35,840	113,300
190	4,990	45,120	158,420
200	6,020	55,050	213,470
210	7,213	66,165	279,635
220	8,493		

PLANS FOR THE DAM.

The map of the reservoir site was made on a scale of 1,000 feet to an inch, with a contour interval of 10 feet. A reduced outline of it is given in Pl. IV. The map of the dam site was made on a scale of 100 feet to an inch, with a contour interval of 5 feet. A reduction is shown in Pl. VII.

The capacity of the reservoir is very large, so far as it goes, but the practicable height of dam is limited by the height of the east abutment. The total excavation to bed rock is large, and much of the material to be excavated is hard. At a depth of 30 feet, more or less, the river gravel is underlain down to bed rock by a very hard cemented mixture of sand and gravel, which would be very expensive to excavate in case a masonry dam was constructed, but is sufficiently firm to serve as foundation for a rock-fill structure. The cost of a masonry dam would be prohibitory. The moderate height, the great length, and the abundance and convenience of suitable rock are all additional arguments in favor of the rock-fill type, and it is without doubt the most suitable. The most unfavorable feature of the whole project is



CROSS SECTION OF McDOWELL DAM.

the character of the east abutment at the dam site. The granite bed rock appears on the surface on the east side of the river, but seems to enter the hill on a nearly horizontal grade. The hill above the granite, which constitutes the upper 90 feet of the abutment, is composed of an indurated mixture of coarse sand and gravel of the same character as the foundation described above, too hard to excavate with a pick, but not to be classified as rock, and inclined to disintegrate upon exposure to the air. It is probable that under high head, water might percolate through this material to some extent, at least where the abutment is thinnest; and to insure against this a concrete core is to be carried into the hill a distance of about 300 yards, where the hill becomes over 1,000 feet thick. Supposing this core to be 6 feet in thickness, the excavation and masonry would cost about $600 per running yard, and hence would add $180,000 to the cost of the construction. The bond between the concrete core and the adjacent natural deposit should be made as thorough as possible by filling the joint with Portland cement concrete, well rammed in place, so that there can be no creeping of water along the wall. With proper precautions it is believed that a dam of the proposed height, 120 feet, could be safely built and maintained.

At the site of the dam the river bed is composed of ordinary sand and gravel to a depth of about 30 feet, when the compact cemented gravel is encountered. The depth to bed rock is about 90 feet at the deepest point. It is proposed to carry a concrete wall down to bed rock across the canyon, at the upstream toe of the dam. This wall will be 35 feet thick at the base on bed rock and diminish to 15 feet at the top. Downstream from this wall the river sand and gravel will be excavated down to the cemented material above mentioned, and upon this will be founded the main dam, which is to be of the rock-fill type, the upstream face to be on a slope of 1 in 2, and the downstream slope 3 in 2, with a top width of 20 feet. The rock will be obtained from the mountain of granite that rises abruptly from the west abutment. The rock can be transported down grade on a cable way, and dropped on the dam in large blocks, from a considerable height, which will serve to ram it solidly in place, and it is believed very little settlement will occur. On the upstream face is to be a wall of rubble masonry resting on the concrete wall that goes down to bed rock. The masonry will have a thickness of 20 feet at the bottom, diminishing to 5 feet at the top. Against its downstream side will be built the mass of dry rock fill; on the water face, which will have a slope of 1 in 2, will be placed, at intervals of 20 feet, a series of 7-inch steel I-beams, each extending from the bottom to the top of the dam. To these beams will be fastened a floor of one-fourth inch steel plates, dipped in asphalt and riveted together to form a water-tight skin over the entire water slope of the dam. The space between the steel plates and the masonry will be filled with concrete tightly rammed. The

concrete and rubble walls will unite at the ends with the concrete core, which is to be carried into the east abutment, as above described.

The outlet will be through a tunnel of concrete built through the dam along the bed of the river, provided with Stoney gates, similar in construction and mechanism to those for the Salt River reservoir, illustrated in Pl. XXII. All water will be drawn from the bottom of the reservoir, and whenever the spillway begins to discharge, the gates will be opened to full capacity for the purpose of discharging the maximum quantity of silt and of reenforcing the spillway.

For diverting the river during construction a temporary diversion dam could be placed across the river about 4,000 feet above the dam site, and the water diverted into a large flume and carried along the east side of the river over the portion of the foundation where granite bed rock appears on the surface. The underflow can probably be sufficiently checked by driving sheet piling down to the bed of indurated gravel, with which the valley is underlain at a depth of about 30 feet. After the dam becomes too high to use this flume the discharge will be through the outlet tunnel. The flume should be removed early in the spring, at the beginning of the low-water season, and construction pushed rapidly, so as to have a large storage and discharge capacity ready for the first flood.

SPILLWAY PROVISIONS.

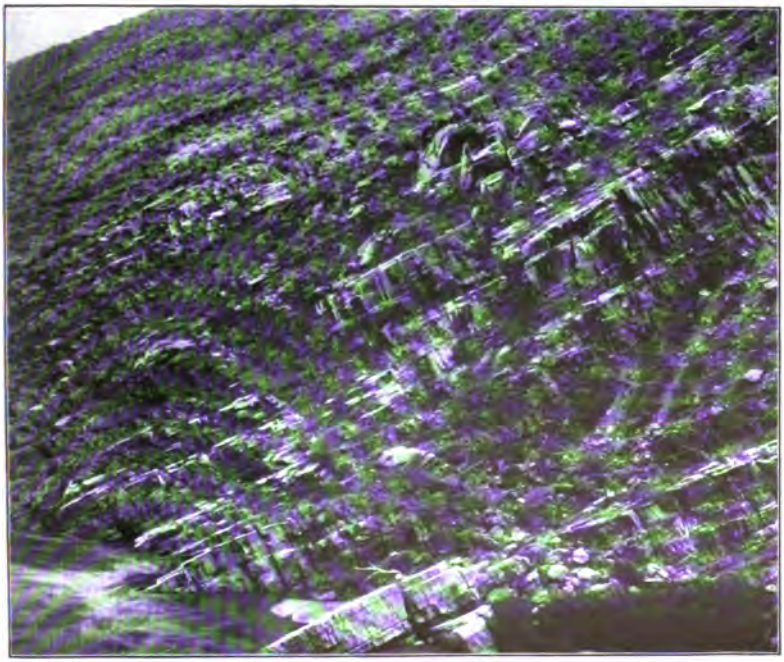
The greatest flood that ever occurred in Salt River Valley since its settlement occurred in February, 1891. It is described in the Twelfth Annual Report[a] of the Geological Survey, as follows:

> On February 17 the mean discharge was 835 second-feet, increasing the next day to 154,000 second-feet, and on the 19th to 276,000. This first flood diminished rapidly, averaging on the 20th only 69,100, and on the 22d 14,890. This was followed by a second swell greater than the first, the flood increasing until, on the 24th, a maximum of 300,000 second-feet was reached. This subsided almost as rapidly as it came, so that by the second day after the river was carrying less than 15,000 second-feet.

The drainage area from which this flood was drawn was considerably more than double that above the McDowell reservoir. A smaller drainage basin is, however, liable to a relatively higher flood discharge than a larger one, though the floods are of shorter duration. It is therefore estimated that the basin under consideration may discharge a flood having a maximum volume of 200,000 cubic feet per second, or two-thirds that of 1891 at Phoenix. On the above assumptions a maximum flood has been hypothecated and the behavior of the reservoir under the circumstances investigated. It is assumed that the reservoir is full up to the bottom of the spillway, and that a great flood discharges 100,000 cubic feet per second on an average for one hour, and increases its discharge 10,000 cubic feet per second during

[a] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, p. 313.

A VIEW IN McDOWELL RESERVOIR BASIN.



B CAPE HORN, SALT RIVER CANYON, SHOWING UPSTREAM DIP OF STRATA.

each hour for eleven hours, at the end of which time it has reached its maximum wave of 200,000 cubic feet per second. The discharge then decreases in an arithmetical progression for twenty hours at the rate of 5,000 second-feet per hour, reaching a discharge of 100,000 second-feet as a mean for the thirty-first hour. The spillway, as planned, has a total length of 900 feet, and its bottom is 15 feet below the top of the dam. Its discharge capacity is computed from the formula $Q=H^{\frac{3}{2}}\ 3150$. Assuming that the gates will be opened to their full capacity when the spillway begins to discharge, the effect on the reservoir of the hypothetical flood is shown in the following table:

Effect of maximum flood in McDowell reservoir with spillway 900 feet long.

[$Q=H^{\frac{3}{2}}\ 3150$.]

Hour.	Inflow.		Outflow.		Net rise.	Elevation.
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.		
					Feet.	
1	100,000	8,260	6,289	518	1.29	201.29
2	110,000	9,090	13,147	1,085	1.28	202.57
3	120,000	9,920	22,759	1,879	1.26	203.83
4	130,000	10,740	34,176	2,822	1.21	205.04
5	140,000	11,570	46,688	3,857	1.15	206.19
6	150,000	12,390	59,856	4,944	1.09	207.28
7	160,000	13,220	73,371	6,060	1.03	208.31
8	170,000	14,040	86,996	7,185	.97	209.28
9	180,000	14,870	100,552	8,297	.91	210.19
10	190,000	15,690	113,506	9,375	.86	211.05
11	200,000	16,520	127,058	10,494	.81	211.86
12	195,000	16,110	138,676	11,455	.62	212.48
13	190,000	15,690	147,681	12,197	.46	212.94
14	185,000	15,290	154,392	12,752	.33	213.27
15	180,000	14,870	159,128	13,144	.22	213.47
16	175,000	14,460	161,896	13,372	.14	213.61
17	170,000	14,040	163,721	13,524	.07	213.68
18	165,000	13,630	164,349	13,576	.00	213.68
19	160,000	13,220	164,000	13,546	− .04	213.64
20	155,000	12,800	162,597	13,430	− .08	213.56
21	150,000	12,390	161,764	13,361	− .13	213.43
22	145,000	11,980	158,353	13,080	− .15	213.28
23	140,000	11,570	155,587	12,851	− .17	213.11
24	135,000	11,150	152,500	12,956	− .19	212.92
25	130,000	10,740	149,136	12,319	− .21	212.71
26	125,000	10,330	145,484	12,016	− .22	212.49
27	120,000	9,920	141,640	11,699	− .24	212.25
28	115,000	9,500	137,602	11,365	− .25	212.00
29	110,000	9,090	133,297	11,101	− .26	211.74
30	105,000	8,680	129,105	10,664	− .27	211.47
31	100,000	8,260	124,739	10,303	− .28	211.19
Capacity			187,975	15,526		215.00

COST.

The following estimate is based upon the data at hand and worked up April 12, 1902, and is subject to modification:

Estimate of the cost of the McDowell reservoir, on Verde River, with capacity of 186,000 acre-feet.

745,875 cubic yards rock fill, at 80 cents a yard	$596,700
78,155 cubic yards dry-laid rubble, at $2 a yard	156,310
7,865 feet, or 117,975 pounds, I beams, at 7 cents a pound	8,258
140,680 square feet quarter-inch plates, or 1,434,936 pounds, at 7 cents a pound	100,445

Excavation, 58,667 cubic yards cemented gravel, at $1 a yard	$58,667
Excavation, 125,000 cubic yards sand, at 20 cents a yard	25,000
5,210 cubic yards of concrete, under steel apron, at $10 a yard	52,100
18,792 cubic yards of concrete in toe wall, at $10 a yard	187,920
Diversion of river	10,000
Outlet, gates, tower, etc	20,000
Concrete core wall to be carried into east abutment	180,000
Engineering and contingencies, 15 per cent	209,331
Right of way	20,000
	1,624,731

Cost per acre-foot capacity, $8.74.

WATER STORAGE ON SALT RIVER.

CHARACTER OF DRAINAGE BASIN.

Salt River, though nominally a tributary of the Gila, really brings far more water to their junction than does the Gila. Though it drains a smaller area, its basin is much higher and cooler and receives an average precipitation far beyond that of the Gila Basin.

The drainage basin of Salt River and its divisions is about as follows:

Area of drainage basin of Salt River.

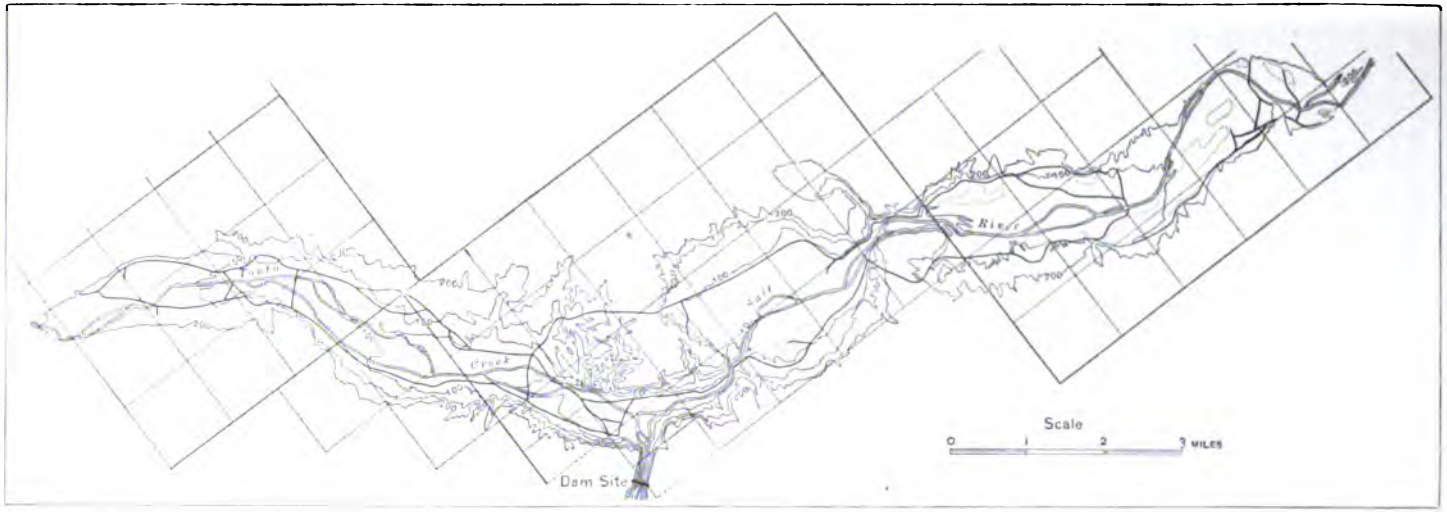
	Square miles.
Salt River at its mouth	12,700
Salt River at Arizona dam	12,260
Verde River near its mouth	6,000
Salt River above mouth of Verde	6,260
Salt River at dam site below Tonto Creek	5,756
Salt River between mouth of Verde and Tonto dam site	504

The elevation at the mouth is about 1,000 feet, while some of the peaks at its headwaters exceed 10,000 feet in altitude, the highest, Thomas Peak, being given as 11,496 feet.

Rather peculiar conditions exist in Salt River Basin, which favor a large water supply relative to its drainage area. In a previous publication the writer has described these conditions, as follows:[a]

The southern portion of the Territory may be again subdivided into two portions, that draining directly into the Colorado and lying to the westward of Prescott, and the greater portion to the south and east, which forms the great Gila River system. The Colorado plateau is partly of igneous origin, and a great portion of it is somewhat pervious to water. Its northern slope for a considerable distance from the summit is very gentle, and though the precipitation is greater than in most portions of the Territory, it is very meagerly marked by drainage lines and almost destitute of water. Sharply contrasted with these facts are the conditions on the southern slope. Here, through most of its course, the plateau drops off with a very steep slope, which is deeply cut with drainage lines in which are living creeks and rivulets of clear, beautiful water, such as San Francisco River, Black Creek, Bonito Creek, White River, Carrizo Creek, Cibicu Creek, Box Creek, Cherry Creek, Tonto Creek, Wild Rye Creek, East Verde River, Pine Creek, Fossil Creek, Clear Creek, Beaver Creek, etc.

[a] Irrigation near Phoenix, Ariz.: Water-Supply and Irrigation Paper, U. S. Geol. Survey, No. 2, p. 15.



OUTLINE OF SALT RIVER RESERVOIR SITE.

The region of high altitude, as before remarked, lies largely north of the divide, while the great bulk of the water flowing from the plateau, as proved both by erosion of drainage lines and by the volume of permanent streams, flows away to the south. The explanation of this is partly the porosity of the strata composing the plateau, which allows the water to sink instead of flowing off the surface. Once underground, its egress to the south is favored by the shorter distance which it must percolate on a given grade before reaching a surface, due to the more abrupt slope.

Another partial explanation is found in the meteorological condition. The moisture of this region is brought from the Pacific Ocean and the Gulf of California by the prevailing southwest wind. As this wind ascends the elevations toward the Colorado Plateau its temperature is lowered, which reduces its capacity for holding moisture and increases its relative humidity. When this quantity reaches 100 per cent in any part, precipitation occurs. This influence continues until the wind passes the summit, where the process is reversed.

As might be expected, therefore, the hydrographic resources of the country immediately southwest of the Colorado Plateau are disproportionately great when compared with those to the northward. For instance, the precipitation at Fort Apache, as shown by a mean of twenty years' observations, is 19.75 inches, the elevation being 5,050 feet, while the precipitation at Holbrook, at an elevation of 5,047 feet, on the northern slope, is 8.47 inches, as indicated by the mean of ten years' observations. This is an important fact, especially when taken in connection with the fact that the great areas of valley land with a semitropic climate lie in the southwestern portion of the Territory, and are easily covered by the streams which are formed by the conditions above described, and which constitute the main features of the great Gila River system.

The topography of the basin of Salt River proper above the mouth of the Verde is nearly all of a rough, mountainous character. The chief tributary above this point is Tonto Creek, and about half a mile below this stream Salt River enters a profound canyon, with precipitous sides and narrow bottom, in which is located the proposed dam site. The Salt and Tonto both occupy comparatively open valleys above this gorge and have a moderate fall. The combined effect is one of the most capacious reservoir sites in the West. The dam might be built to a height of 300 feet or more, if such a height were justified by the water supply.

WATER SUPPLY.

The only available rainfall observations in the basin tributary to the proposed reservoir are those at Payson and Camp Apache. The record at Payson is so short and broken that it is of no real value in the discussion of the water supply, so only that of Camp Apache remains. Fortunately this station is located near the center of the basin, and the record is reliable and complete from 1876 to date—about twenty-six years. This affords excellent means of obtaining monthly and annual maxima, minima, and means at this point, which, so far as known, may be assumed to represent an average of the entire basin as nearly as any one point that might be selected.

Precipitation, in inches, at Camp Apache.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1876	0.92	1.72	2.02	0.08	0.26	1.02	5.20	2.52	2.00	2.44	1.34	0.22	19.74
1877	.36	.94	.72	.96	1.15	.00	3.11	1.20	.99	.81	.19	2.07	12.50
1878	.18	1.35	2.41	1.77	.18	.79	8.76	9.33	.76	.00	1.94	1.14	28.61
1879	1.89	1.17	.08	.12	.00	.05	3.92	3.06	1.52	2.64	1.77	2.41	18.58
1880	1.31	.95	.80	.46	.00	.46	5.83	1.44	.55	.56	.03	2.38	14.77
1881	.20	1.17	2.45	1.53	.35	T.	5.63	8.31	5.41	4.68	.85	.54	31.12
1882	2.82	2.85	1.09	.91	.94	3.27	4.79	7.36	1.02	T.	2.34	.23	27.62
1883	.85	2.46	2.03	.22	.86	.02	5.46	4.26	.60	1.39	.02	3.48	21.65
1884	.68	3.43	4.44	1.67	1.31	2.35	.14	5.59	1.50	2.02	.82	5.52	29.47
1885	.52	1.00	2.05	.52	1.12	.82	2.60	3.16	.44	.38	1.56	1.41	15.58
1886	3.90	2.73	1.06	.91	.00	.19	1.90	4.75	3.16	1.66	.56	.24	21.06
1887	.59	2.16	.04	.81	.15	1.70	3.29	3.92	2.23	.55	1.83	.57	17.84
1888	1.42	1.83	2.92	.71	.71	T.	3.24	[1.00]	.32	1.23	2.63	2.88	18.89
1889	2.24	.88	1.85	.47	.00	.11	2.67	2.87	1.02	.46	.55	3.98	17.10
1890	2.26	2.40	.82	1.39	.00	.00	5.00	4.44	2.37	2.17	2.85	3.02	26.72
1891	1.65	4.10	.85	T.	.36	T.	2.72	1.22	1.81	.00	.00	.65	13.36
1892	.65	2.29	2.22	1.36	.36	.15	1.33	1.30	1.23	.55	.57	.69	12.70
1893	.28	1.10	2.45	.00	2.18	.00	2.57	3.43	2.65	.04	.28	.10	15.38
1894	1.24	.96	1.36	.19	.79	.00	1.27	5.01	1.32	2.47	.00	2.81	17.42
1895	1.89	.72	.02	T.	1.00	.01	.74	5.44	1.68	3.02	2.39	1.12	18.03
1896	.16	.33	.86	.34	.00	.52	4.31	4.36	1.34	2.42	.77	.68	16.09
1897	2.23	1.40	1.79	.24	.34	.37	1.20	2.07	3.41	1.30	.00	.57	14.92
1898	2.76	1.50	1.08	.50	2.70	2.60	4.33	3.59	.12	.00	.57	.80	20.55
1899	1.33	1.04	.17	.45	.00	1.90	4.55	.96	1.52	.82	.71	1.60	15.05
1900	.30	.29	1.15	1.75	.10	.00	.82	1.31	2.79	.77	4.86	T.	14.14
1901	2.87	2.60	1.20	.20	1.15	.00	3.38	1.45	.45	1.22	.65	1.80	16.97

Measurements of the flow near the dam site below Tonto Creek were begun in February, 1901, and are still continued. Besides these there are records of flow of Salt River above the mouth of the Verde from April, 1897, to November 30, 1899, and of Salt River below the Verde for several previous years and for 1900. The measurements below the Verde are made in the various irrigation canals. When there was a surplus of water, there was no necessity for accurate measurements, and at such times the results are only approximate. They are, however, for a considerable period the only available records, and are considered sufficiently accurate to justify their use. To render available the latter records in estimating the water supply to the proposed reservoir, it is necessary to determine the proportion of water received from the Verde and Salt. For this purpose the records are taken where these two streams were separately observed, and the ratio of each stream to their sum is computed month by month, with results as given below:

Proportion of total flow of Salt and Verde rivers discharged by Salt River.

Month.	1897.	1898.	1899.	1901.	Mean.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	
January	.....	0.587	0.520	0.615	0.574
February	.....	.555	.541	.539	.545
March	.....	.531	.660	.631	.607
April	.....	.720	.740	.855	.772
May	0.818	.719	.862	.836	.808
June	.720	.647	.590	.728	.672
July	.575	.573	.564	.567	.570
August	.495	.508	.619	.425	.510
September	.419	.516	.469	.657	.515
October	.654	.494	.828	.....	.492
November	.523	.522	.461	.....	.502
December	.515	.504	.....	.....	.....

A GORGE OF SALT RIVER LOOKING DOWNSTREAM.

B. SALT RIVER RESERVOIR SITE, LOOKING UPSTREAM.

The values thus obtained cover the periods from August 1, 1888, to December 31, 1894, and from December 1, 1899, to December 31, 1900. Observations of the discharge of Salt River above the Verde were taken direct from February 4, 1895, to July 31, 1896. During this period direct observations were made by the Hudson Reservoir Company, and from April 20, 1897, to November 30, 1899, by the Geological Survey. The discharge from February 27 to December 31, 1901, was observed at the reservoir site and requires no reduction.

The storage of flood waters on Salt River will not only utilize such waters by holding them until needed, but will greatly increase the utility of the floods of the Verde River by providing a much larger irrigated area to receive such floods, and at the same time holding back the waters of the Salt as long as the Verde is able to fill the requirements. An examination of the records shows that with such manipulation the Verde will usually supply all requirements during the four months of December, January, February, and March, and that a very large proportion of the flood waters of the Verde which now run to waste would be thus utilized.

The record since 1888 is taken in connection with the proposed reservoir and 660,000 acre-feet annual consumption, and from this a table has been constructed, showing what would take place if the past experience should be repeated after the construction of the reservoir.

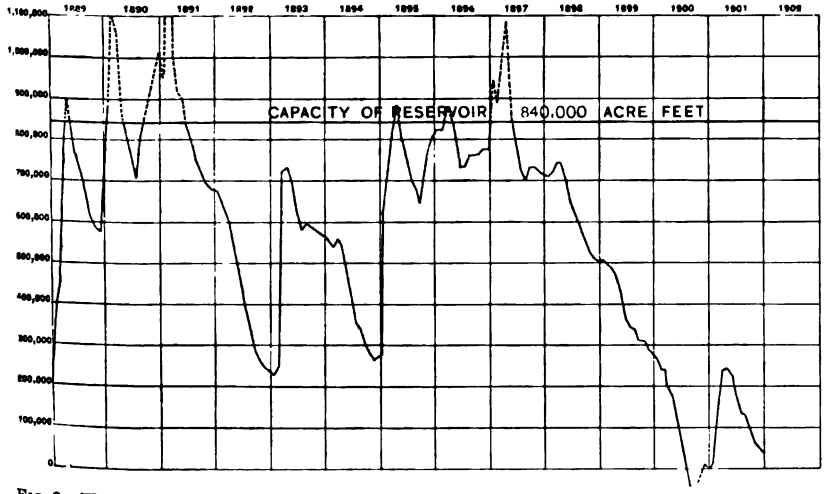


FIG. 2.—Fluctuations of Salt River reservoir, operated in connection with Verde River, under a duty of 660,000 acre-feet per annum.

The drainage area between the reservoir and the mouth of the Verde is nearly 10 per cent of the whole area above the Verde, and therefore to reduce the discharge of the Salt to that intercepted at the reservoir, the discharge at the mouth of the Verde was reduced by about 10 per cent, this percentage being slightly modified according to the season. From these data and computations the tables of dis-

charges for the Verde, at McDowell, and Salt River at the reservoir site, were obtained. In reducing the discharge of Arizona dam to the required amounts, the following percentages were used:

Estimated monthly discharge at McDowell and Salt River reservoir sites, in percentage of total at Arizona dam.

Month.	Verde at McDowell.	Salt at reservoir site.	Month.	Verde at McDowell.	Salt at reservoir site.
January	0.42	0.52	August	0.49	0.46
February	.45	.50	September	.48	.46
March	.39	.56	October	.50	.44
April	.20	.72	November	.50	.45
May	.19	.76	December	.50	.45
June	.30	.63			
July	.42	.52	Mean	.40	.54

Estimated monthly discharge of Salt River at reservoir site.

[Drainage area, 5,756 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1888.[a]						
August			161	9,902	.03	.03
September			161	9,580	.03	.03
October	154	132	146	8,957	.02	.02
November	2,592	191	379	22,545	.06	.07
December	19,570	249	3,014	185,367	.52	.58
The year				236,351		
1889.[a]						
January	12,976	866	2,092	190,185	.54	.62
February	1,970	767	1,303	72,289	.23	.24
March	18,925	1,995	4,897	301,178	.85	.98
April	4,002	1,797	2,862	170,289	.50	.56
May	1,356	473	790	48,562	.14	.16
June	387	224	296	17,618	.05	.06
July	682	174	257	15,871	.04	.05
August	347	179	192	11,797	.03	.03
September	539	179	240	14,280	.04	.04
October	310	140	194	11,906	.03	.03
November	283	239	259	15,422	.04	.04
December	11,417	251	2,561	157,360	.44	.51
The year	18,925	174	1,420	1,026,737	.24	3.32
1890.[a]						
January	8,190	716	2,591	159,324	.45	.52
February	71,644	523	5,049	280,192	.88	.92
March	9,648	1,437	3,596	221,139	.62	.71
April	1,495	986	1,325	78,826	.23	.26
May	1,040	479	695	42,720	.12	.13
June	423	250	322	19,155	.06	.07
July	453	206	272	16,758	.05	.06
August	3,538	512	1,787	109,906	.31	.36
September	1,695	334	1,076	64,018	.20	.22
October	3,285	331	1,218	70,502	.21	.24
November	13,727	345	2,123	126,297	.37	.41
December	13,665	500	2,817	173,218	.49	.56
The year	71,644	206	1,906	1,362,055	.33	4.46
1891.[a]						
January	8,906	551	1,777	109,254	.31	.36
February	150,000	413	19,408	1,077,834	3.37	3.47
March	4,968	753	2,768	170,204	.48	.55
April	2,182	1,654	1,922	114,390	.33	.37
May	2,243	1,461	1,834	112,761	.32	.37
June	1,132	587	842	50,083	.15	.17
July	502	312	388	23,884	.07	.08
August	346	236	261	16,066	.04	.05

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.

A. DRILLING PARTY ON SALT RIVER, LINE A OF BORINGS.

B. SALT RIVER DAM SITE, LOOKING DOWNSTREAM.

Estimated monthly discharge of Salt River at reservoir site—Continued.

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1891.[a]						
September	605	220	378	22,500	.07	.08
October	273	203	227	13,963	.04	.05
November	283	207	230	13,710	.04	.04
December	311	264	295	14,151	.05	.06
The year	150,000	203	2,529	1,738,770	.44	5.65
1892.						
January	445	318	352	21,614	.06	.07
February[b]	234	204	221	12,274	.04	.04
March[b]	268	206	230	14,118	.04	.04
April[b]	450	268	315	18,765	.05	.06
May[b]	760	185	365	22,431	.06	.07
June[b]	157	76	110	6,523	.02	.02
July	267	168	189	11,606	.03	.03
August	259	152	186	11,427	.03	.03
September	180	150	157	9,361	.03	.03
October	770	144	196	12,066	.03	.03
November	392	208	231	13,736	.04	.04
December	266	236	253	14,578	.04	.05
The year	770	76	234	168,499	.04	.51
1893.						
January	286	286	286	17,585	.05	.06
February	5,312	275	747	41,459	.13	.13
March	207,208	331	7,734	475,523	1.34	1.54
April	1,782	508	1,043	62,079	.18	.20
May	1,520	257	602	37,010	.14	.16
June	222	93	143	8,509	.02	.02
July	592	145	279	17,138	.05	.06
August	1,164	219	753	46,301	.13	.15
September	1,116	272	508	30,218	.09	.10
October	655	242	331	20,345	.05	.06
November	305	252	266	15,852	.04	.04
December	293	281	283	17,404	.05	.06
The year	207,208	93	1,081	789,423	.18	2.58
1894.						
January	327	286	306	18,609	.05	.06
February	316	263	288	15,995	.05	.05
March	1,430	294	760	46,761	.13	.15
April	968	342	616	36,673	.10	.11
May	356	241	271	16,636	.05	.06
June	280	139	166	9,897	.03	.03
July	276	82	148	9,081	.02	.02
August	866	131	412	25,343	.07	.08
September	685	133	280	16,642	.05	.06
October	628	107	213	13,094	.04	.05
November	272	186	207	12,290	.03	.03
December	738	209	397	24,432	.07	.08
The year	1,430	82	338	245,453	.06	.78
1895.						
January[c]	46,806	744	5,390	331,358	.93	1.07
February[c]	3,697	368	1,373	76,239	.24	.25
March[c]	3,173	1,253	1,738	106,838	.30	.35
April[c]	2,704	961	1,711	105,144	.30	.33
May[c]	940	480	673	41,356	.12	.14
June[c]	475	193	309	18,372	.05	.06
July[d]	353	120	160	9,816	.03	.03
August[d]	1,022	209	440	27,168	.08	.09
September[d]	499	166	242	14,425	.04	.04
October[d]	7,194	279	857	52,675	.15	.17
November[d]	3,994	309	764	45,467	.13	.15
December[d]	995	430	603	37,104	.10	.12
The year	46,806	120	1,188	865,962	.20	2.80

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.
[b] Approximate; filled in from minimum discharge recorded in same months for 1900.
[c] Results obtained by taking from the published discharge of Salt River at McDowell (Eighteenth Ann. Rept., Pt. IV, p. 298) that percentage of the whole that represents the discharge of the Salt between the mouth of the Verde and the reservoir site.
[d] Results obtained by taking proportional part of the discharge of Salt River at Arizona dam. Mr. Trott's figures used in computation.

Estimated monthly discharge of Salt River at reservoir site—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1896.[a]						
January	547	416	447	27,497	.08	.09
February	479	389	398	22,572	.07	.07
March	1,769	428	844	51,925	.15	.17
April	1,487	636	941	55,986	.16	.18
May	669	352	485	29,861	.08	.09
June	292	150	204	12,245	.08	.08
July	5,528	111	779	47,928	.13	.15
August	4,997	256	797	49,017	.14	.16
September	4,280	241	534	31,752	.09	.10
October	555	265	398	24,484	.07	.08
November	672	300	443	26,375	.08	.09
December	400	298	317	19,479	.05	.05
The year	5,528	111	548	399,121	.08	1.26
1897.						
January[a]	19,422	312	2,647	162,777	.46	.53
February[a]	2,494	543	970	53,871	.17	.18
March[a]	5,762	1,013	2,160	132,808	.38	.44
April	9,743	1,136	4,281	254,787	.74	.83
May[b]	1,910	608	1,114	68,461	.19	.22
June[b]	591	180	358	21,305	.06	.07
July[b]	285	78	175	10,173	.03	.03
August[b]	755	157	410	25,176	.07	.08
September[b]	1,269	338	673	40,049	.11	.12
October[b]	1,010	228	549	33,755	.09	.10
November[b]	290	257	273	16,225	.05	.06
December[b]	292	251	270	16,590	.05	.06
The year	19,422	78	1,157	835,977	.20	2.72
1898.[c]						
January	1,077	240	338	20,808	.06	.07
February	743	473	587	32,511	.10	.10
March	858	509	688	42,261	.12	.14
April	1,036	496	757	45,000	.13	.14
May	704	261	448	27,513	.08	.09
June	351	182	237	14,112	.04	.04
July	800	166	408	25,085	.07	.08
August	1,211	130	385	23,658	.06	.07
September	868	106	338	20,136	.06	.07
October	180	106	156	9,538	.03	.03
November	232	182	202	12,041	.03	.03
December	402	232	300	18,401	.05	.06
The year	1,211	106	404	291,064	.07	.92
1899.[c]						
January	762	249	356	21,906	.06	.07
February	461	332	386	21,421	.06	.06
March	617	404	480	29,499	.08	.09
April	575	437	536	32,025	.09	.10
May	475	204	308	18,926	.05	.06
June	493	161	204	12,119	.03	.03
July	1,410	155	444	27,282	.08	.09
August	3,325	166	671	41,240	.11	.13
September	1,228	165	298	17,675	.05	.06
October	738	158	253	15,548	.04	.05
November	215	157	203	12,040	.03	.03
December[d]	203	142	195	12,009	.03	.03
The year	3,325	142	361	261,690	.06	.80
1900.[e]						
January	242	222	234	14,388	.04	.05
February	234	204	221	12,274	.04	.04
March	268	206	230	14,118	.04	.05
April	450	268	315	18,765	.05	.06
May	760	185	365	22,431	.06	.07

[a] Mr. Trotts's figures used in these computations. Results obtained by taking proportional parts of the discharge of Salt River at Arizona dam.

[b] Results obtained by taking from the discharge registered at McDowell that percentage which represents the discharge of the river between McDowell and the reservoir site.

[c] Results obtained by taking from the discharge registered at McDowell that part of percentage that represents the discharge of the river between McDowell and reservoir site.

[d] Trott's figures.

[e] Computations made from Mr. F. P. Trott's figures.

A. SALT RIVER DAM SITE, LOOKING UPSTREAM.

B. SOUTH ABUTMENT OF SALT RIVER DAM, LOOKING DOWNSTREAM.

Estimated monthly discharge of Salt River at reservoir site—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.[a]						
June	157	76	110	6,523	.02	.02
July	130	45	64	3,933	.01	.01
August	521	63	142	8,711	.02	.02
September	290	88	116	6,898	.02	.02
October	359	95	161	9,902	.03	.03
November	2,222	146	387	23,055	.06	.07
December	245	184	202	12,398	.03	.03
The year	2,222	45	212	153,394	.035	.47
1901.						
January[a]	1,735	201	454	27,945	.08	.09
February[b]	4,172	928	2,414	134,047	.42	.44
March[b]	3,468	740	1,423	87,472	.25	.29
April[b]	1,562	620	1,050	62,442	.18	.20
May[b]	1,267	462	735	45,203	.13	.15
June[b]	508	147	288	17,282	.05	.06
July[b]	3,556	71	346	21,296	.06	.07
August[b]	2,221	207	529	32,504	.09	.10
September[b]	670	123	309	17,907	.05	.06
October[b]	215	117	152	9,334	.03	.03
November[b]	215	183	189	10,629	.03	.03
December[b]	195	183	190	11,663	.03	.03
The year	4,172	71	672	477,704	.11	1.55
1902.						
January	238	170	186	11,423	.03	.03
February	220	184	194	10,852	.03	.03

[a] Computations made from Mr. F. P. Trott's figures.
[b] Computations made from observations by United States Geological Survey.

History of Salt River Reservoir, operated from 1889 to 1901, in connection with the unregulated Verde River, with annual use of 660,000 acre-feet.

[Capacity of reservoir, 840,745 acre-feet. Annual use, 660,000 acre-feet.]

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
1889.		*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
January	6	39,600	153,611	0	0.25	6,874	1,718	1,718	190,185	200,000 388,467	.....
February	7	46,200	65,059	0	.34	8,676	2,950	2,950	72,289	457,806	.....
March	8	52,800	209,747	0	.50	10,895	5,448	5,448	301,178	753,536	.....
April	9	59,400	47,302	12,098	.58	12,361	7,169	19,267	170,289	840,745	63,813
May	11	72,600	12,141	60,459	.83	13,398	11,120	75,330	48,562	813,977	.....
June	11	72,600	8,390	64,210	.92	12,950	11,914	76,124	17,618	755,471	.....
July	10	66,000	12,819	53,181	1.00	12,408	12,408	65,584	15,871	705,758	.....
August	10	66,000	12,556	53,444	1.08	11,821	12,767	66,210	11,797	651,345	.....
September	9	59,400	14,880	44,520	.83	11,231	9,332	53,841	14,260	611,764	.....
October	7	46,200	13,530	32,670	.50	10,796	5,398	38,068	11,906	585,602	.....
November	6	39,600	17,136	22,464	.42	10,596	4,450	26,914	15,422	574,110	.....
December	6	39,600	174,845	0	.33	11,433	3,773	3,773	157,360	727,697	.....
1890.											
January	6	39,600	128,685	0	.25	13,233	3,308	3,308	159,324	840,745	42,968
February	7	46,200	252,172	0	.34	13,459	4,576	4,576	280,192	840,745	275,616
March	8	52,800	153,967	0	.50	13,459	6,729	6,729	221,139	840,745	214,410
April	9	59,400	21,896	37,504	.58	13,459	7,806	45,310	78,826	840,745	33,516
May	11	72,600	10,680	61,920	.83	13,362	10,190	72,110	42,720	811,355	.....
June	11	72,600	9,121	63,479	.92	12,935	11,900	75,379	19,155	755,131	.....
July	10	66,000	13,535	52,465	1.00	12,408	12,408	64,873	16,758	707,016	.....
August	10	66,000	117,074	0	1.08	12,659	13,671	13,671	109,906	803,251	.....
September	9	59,400	66,802	0	.83	13,404	11,125	11,125	64,018	840,745	15,399
October	7	46,200	80,116	0	.50	13,459	6,729	6,729	70,502	840,745	63,773
November	6	39,600	140,331	0	.42	13,459	5,652	5,652	126,297	840,745	120,645
December	6	39,600	192,464	0	.33	13,459	4,440	4,440	173,218	840,745	168,778

History of Salt River Reservoir, operated from 1889 to 1901, etc.—Continued.

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
		Acre-ft.	*Acre-ft.*	*Acre-ft*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft*
1891.											
January	6	39,600	88,244	0	.25	13,459	3,365	3,365	109,204	840,745	105,839
February	7	46,200	970,051	0	.34	13,459	4,576	4,576	1,077,834	840,745	1,073,258
March	8	52,800	118,535	0	.50	13,459	6,730	6,730	170,204	840,745	163,474
April	9	59,400	31,775	27,625	.58	13,459	7,806	35,431	114,390	840,745	78,959
May	11	72,600	28,190	44,410	.83	13,459	11,170	55,580	112,761	840,745	57,181
June	11	72,600	23,849	48,751	.92	13,459	12,382	61,133	50,083	829,695	.....
July	10	66,000	19,291	46,709	1.00	13,231	13,231	59,940	23,884	793,639	.....
August	10	66,000	17,113	48,887	1.08	12,814	13,839	62,726	16,066	746,977	.....
September	9	59,400	23,478	35,922	.83	12,438	10,323	46,245	22,500	719,232	.....
October	7	46,200	15,833	30,367	.50	12,138	6,069	36,436	13,935	696,729	.....
November	6	39,600	15,233	24,367	.42	11,840	4,973	29,340	13,710	681,099	.....
December	6	39,600	20,168	19,432	.33	11,744	3,875	23,307	14,151	674,943	.....
1892.											
January	6	39,600	17,458	22,142	.25	11,698	2,925	25,067	21,614	671,490	.....
February	7	46,200	11,746	34,454	.34	11,525	3,918	38,372	12,274	645,392	.....
March	8	52,800	7,087	45,713	.50	11,151	5,575	51,288	14,118	608,222	.....
April	9	59,400	4,604	54,796	.58	10,684	6,197	60,992	18,765	565,995	.....
May	11	72,600	5,935	66,665	.83	10,183	8,452	58,213	22,431	507,782	.....
June	11	72,600	3,588	69,012	.92	9,282	8,549	77,561	6,523	436,744	.....
July	10	66,000	9,374	56,626	1.00	8,518	8,518	65,144	11,606	383,206	.....
August	10	66,000	12,172	53,828	1.08	7,792	8,415	62,243	11,427	332,210	.....
September	9	59,400	9,768	49,632	.83	7,098	5,891	55,523	9,361	286,048	.....
October	7	46,200	13,712	32,488	.50	6,621	3,310	35,798	12,066	262,316	.....
November	6	39,600	15,263	24,337	.42	6,300	2,646	26,983	13,736	249,069	.....
December	6	39,600	17,309	22,291	.33	6,202	2,046	24,337	14,578	239,310	.....
1893.											
January	6	39,600	14,204	25,396	.25	6,061	1,515	26,911	17,585	229,984	.....
February	7	46,200	25,502	20,698	.34	6,133	2,085	22,783	41,459	248,660	.....
March	8	52,800	331,168	0	.50	9,533	4,767	4,767	475,523	719,416	.....
April	9	59,400	17,244	42,156	.58	12,328	7,150	49,306	62,079	732,189	.....
May	11	72,600	9,252	63,348	.83	12,223	10,145	73,493	37,010	695,706	.....
June	11	72,600	4,052	68,548	.92	11,589	10,662	79,210	8,509	625,005	.....
July	10	66,000	13,842	52,158	1.00	10,825	10,825	62,983	17,138	579,160	.....
August	10	66,000	49,321	16,679	1.08	10,297	11,120	27,800	46,301	597,661	.....
September	9	59,400	31,532	27,868	.83	12,168	10,099	37,967	30,218	589,912	.....
October	7	46,200	23,120	23,080	.50	10,666	5,333	28,413	20,345	581,844	.....
November	6	39,600	17,613	21,987	.42	10,561	4,435	26,422	15,852	571,274	.....
December	6	39,600	19,388	20,212	.33	10,464	3,453	23,665	17,404	565,013	.....
1894.											
January	6	39,600	15,030	24,570	.25	10,347	2,587	27,157	18,009	556,465	.....
February	7	46,200	14,395	31,805	.34	10,234	3,480	35,285	15,995	537,175	.....
March	8	52,800	32,565	20,235	.50	10,254	5,127	25,362	46,761	558,574	.....
April	9	59,400	10,187	49,213	.58	10,279	6,162	55,375	36,673	539,872	.....
May	11	72,600	4,159	68,441	.83	9,860	8,184	76,625	16,636	479,883	.....
June	11	72,600	4,713	67,887	.92	9,040	8,317	76,204	9,897	413,579	.....
July	10	66,000	7,334	58,666	1.00	8,173	8,173	66,839	9,081	355,821	.....
August	10	66,000	26,966	39,034	1.08	7,510	8,111	47,145	25,343	334,019	.....
September	9	59,400	17,365	42,035	.83	7,052	5,853	47,888	16,642	302,773	.....
October	7	46,200	14,880	31,320	.50	6,855	3,427	34,747	13,094	281,120	.....
November	6	39,600	13,656	25,944	.42	6,601	2,772	28,716	12,290	264,694	.....
December	6	39,600	27,147	12,453	.33	6,554	2,162	14,615	24,432	274,511	.....
1895.											
January	6	39,600	248,225	0	.25	9,039	2,260	2,260	352,508	624,759	.....
February	7	46,200	93,747	0	.34	11,579	3,937	3,937	80,251	701,073	.....
March	8	52,800	228,734	0	.50	12,611	6,305	6,305	112,461	807,229	.....
April	9	59,400	30,591	28,809	.58	13,459	7,806	36,615	110,678	840,745	40,547
May	11	72,600	15,864	56,736	.83	13,392	11,115	67,851	43,533	816,427	.....
June	11	72,600	9,104	63,496	.92	12,987	11,948	75,444	19,339	760,422	.....
July	10	66,000	8,916	57,084	1.00	12,417	12,417	69,501	12,543	703,464	.....
August	10	66,000	22,074	43,926	1.08	11,828	12,774	56,700	35,909	682,673	.....
September	9	59,400	10,473	48,927	.83	11,617	9,642	58,569	19,577	643,681	.....
October	7	46,200	20,630	25,570	.50	11,772	5,886	31,456	99,856	712,081	.....
November	6	39,600	27,550	12,050	.42	12,607	5,253	17,303	81,878	776,656	.....
December	6	39,600	24,042	15,558	.33	13,006	4,292	19,850	54,601	811,407	.....
1896.											
January	6	39,600	25,382	14,218	.25	13,235	3,309	17,527	28,900	822,780	.....
February	7	46,200	22,577	23,623	.34	13,296	4,520	28,143	27,380	822,017	.....
March	8	52,800	40,798	12,002	.50	13,459	6,780	18,782	72,863	840,745	35,353
April	9	59,400	21,776	37,624	.58	13,459	7,806	45,430	57,061	840,745	11,631
May	11	72,600	9,430	63,170	.83	13,277	11,020	74,190	27,424	793,979	.....
June	11	72,600	7,133	65,467	.92	12,719	11,701	77,168	13,328	730,139	.....
July	10	66,000	44,241	21,759	1.00	12,425	12,425	34,184	39,292	735,247	.....

A. MARICOPA COUNTY WATER-STORAGE COMMISSIONERS INSPECTING PLANE-TABLE WORK.

B. CLAY HILLS NORTH EDGE OF RESERVOIR SITE.

History of Salt River Reservoir, operated from 1889 to 1901, etc.—Continued.

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
		Acre-ft.	*Acre-ft.*	*Acre-ft.*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
1896.											
August	10	66,000	57,541	8,459	1.08	12,593	13,600	22,059	49,017	762,205	.....
September	9	59,400	37,273	22,127	.83	12,710	10,549	32,676	31,752	761,281	.....
October	7	46,200	31,161	15,039	.50	12,700	6,350	21,389	24,484	764,376	.....
November	6	39,600	32,226	7,374	.42	12,780	5,367	12,741	26,375	778,010	.....
December	6	39,600	23,808	15,792	.33	12,840	4,237	20,029	19,479	777,460	.....
1897.											
January	6	39,600	150,158	0	.25	13,459	3,365	3,365	162,777	840,745	96,127
February	7	46,200	53,871	0	.34	13,459	4,576	4,576	53,871	840,745	49,295
March	8	52,800	104,350	0	.50	13,459	6,730	6,730	132,808	840,745	126,078
April	9	59,400	99,084	0	.58	13,459	7,806	7,806	254,787	840,745	246,981
May	11	72,600	20,143	52,457	.83	13,459	11,170	63,627	68,461	840,745	5,034
June	11	72,600	10,524	62,076	.92	13,248	12,188	74,264	21,305	787,786	.....
July	10	66,000	8,643	57,357	1.00	12,681	12,681	70,038	10,173	727,921	523,515
August	10	66,000	28,318	37,682	1.08	12,249	13,229	50,910	25,176	702,187	.....
September	9	59,400	61,584	0	.83	12,225	10,171	10,171	40,049	732,065	.....
October	7	46,200	21,154	25,046	.50	12,400	6,200	31,246	33,755	734,574	.....
November	6	39,600	16,443	23,157	.42	12,345	5,185	28,342	16,225	722,457	.....
December	6	39,600	17,290	22,310	.33	12,228	4,035	26,345	16,590	712,702	.....
1898.											
January	6	39,600	16,884	22,716	.25	12,156	3,039	25,755	20,808	707,755	.....
February	7	46,200	29,357	16,843	.34	12,190	4,145	20,628	32,511	719,638	.....
March	8	52,800	41,547	11,253	.50	12,387	6,198	17,451	42,261	744,448	.....
April	9	59,400	22,894	36,506	.58	12,524	7,364	43,870	45,000	745,578	.....
May	11	72,600	12,762	59,838	.83	12,328	10,231	70,069	27,513	703,022	.....
June	11	72,600	9,333	63,267	.92	11,744	10,804	74,071	14,112	643,162	.....
July	10	66,000	21,462	44,538	1.00	11,153	11,153	55,688	25,085	612,560	.....
August	10	66,000	25,840	40,160	1.08	10,845	11,713	51,873	23,658	584,345	.....
September	9	59,400	21,397	38,003	.83	10,528	8,738	46,741	26,136	557,740	.....
October	7	46,200	10,999	35,201	.50	10,194	5,097	40,298	9,538	526,980	.....
November	6	39,600	12,236	27,364	.42	9,928	4,170	31,534	12,041	507,487	.....
December	6	39,600	19,399	20,201	.83	9,780	3,227	23,428	18,401	502,460	.....
1899.											
January	6	39,600	22,919	16,681	.25	9,763	2,441	19,122	21,906	505,244	.....
February	7	46,200	20,232	25,968	.34	9,741	3,312	29,279	21,421	497,386	.....
March	8	52,800	17,539	35,261	.50	9,645	4,823	40,084	29,499	486,801	.....
April	9	59,400	14,983	44,417	.58	9,341	5,418	49,835	32,025	468,991	.....
May	11	72,600	10,342	62,258	.83	8,990	7,462	69,720	18,726	418,197	.....
June	11	72,600	9,967	62,633	.92	7,873	7,243	69,876	12,119	360,440	.....
July	10	66,000	24,183	41,817	1.00	7,667	7,667	49,484	27,282	338,238	.....
August	10	66,000	28,856	37,144	1.08	7,481	8,079	45,223	41,240	334,255	.....
September	9	59,400	22,371	37,029	.83	7,259	6,025	43,054	17,675	308,876	.....
October	7	46,200	34,749	11,451	.50	7,082	3,541	14,992	15,548	309,432	.....
November	6	39,600	13,874	25,726	.42	6,973	2,929	28,755	12,040	292,817	.....
December	6	39,600	14,677	24,923	.33	6,602	2,178	27,101	12,009	277,765	.....
1900.											
January	6	39,600	13,281	26,319	.25	6,568	1,642	27,961	14,388	264,192	.....
February	7	46,200	12,373	32,927	.34	6,320	2,149	36,076	12,274	240,390	.....
March	8	52,800	11,092	41,708	.50	5,935	2,967	44,675	14,118	209,833	.....
April	9	59,400	7,298	52,102	.58	5,404	3,134	55,236	18,765	173,362	.....
May	11	72,600	7,083	65,517	.83	4,450	3,693	69,210	22,431	126,583	.....
June	11	72,600	3,840	68,760	.92	3,477	3,199	71,959	6,523	61,147	.....
July	10	66,000	3,630	62,370	1.00	1,440	1,440	63,810	3,933	1,270	.....
August	10	66,000	10,226	55,774	1.08	0	0	0	8,711	.....	−45,793
September	9	59,400	8,097	51,303	.83	0	0	0	6,898	.....	−44,405
October	7	46,200	12,602	33,598	.50	0	0	0	9,902	.....	−23,606
November	6	39,600	28,178	11,422	.42	401	168	11,590	23,055	11,465	.....
December	6	39,600	15,150	24,450	.33	382	126	24,576	12,396	.....	− 715
1901.											
January	6	39,600	28,704	10,896	.25	549	137	11,033	27,945	16,912	.....
February	7	46,200	108,249	0	.34	3,112	1,058	1,058	134,047	149,901	.....
March	8	52,800	63,688	0	.50	5,417	2,709	2,709	87,472	234,664	.....
April	9	59,400	10,938	48,462	.58	6,151	3,568	52,030	62,442	245,076	.....
May	11	72,600	8,606	63,994	.83	6,065	5,034	69,028	45,203	221,251	.....
June	11	72,600	6,222	66,378	.92	5,465	5,027	71,405	17,262	167,108	.....
July	10	66,000	12,916	53,084	1.00	4,436	4,436	57,520	21,296	131,884	.....
August	10	66,000	38,561	27,439	1.08	4,130	4,460	31,899	32,504	132,489	.....
September	9	59,400	5,514	53,886	.83	3,780	3,137	57,023	17,907	93,373	.....
October	7	46,200	8,210	37,990	.50	3,004	1,502	39,492	9,334	63,215	.....
November	6	39,600	15,238	24,362	.42	2,290	962	25,363	10,629	48,481	.....
December	6	39,600	16,485	23,115	.33	1,761	581	23,696	11,663	36,346	.....

This table shows that if the proposed reservoir were operated in conjunction with the natural flow of the Verde River, and an annual supply of 660,000 acre-feet were desired, this could have been furnished every year in the record except 1900. In that year there would have been a shortage of about 16 per cent. It is believed that such a shortage is permissible in a storage project if it does not occur oftener than once in say ten years, which is the fact in the present case.

The duty of 660,000 acre-feet per annum is that of the combined Salt and Verde rivers, with a reservoir on Salt River operated in conjunction with the Verde, the waters of Salt River being held in the reservoir as long as the waters of the Verde are sufficient to supply demands. If the flood waters of the Verde are to be stored and used independent of Salt River they will not be available for this use, and the manipulation of Salt River reservoir will be radically different. Under these conditions the draft on the reservoir becomes constant the year around; the requirement for storage is lessened, and the irrigation duty of Salt River alone is of course much less. Our records indicate that a duty of about 450,000 acre-feet can be depended upon by using the rest of our storage capacity for reserve storage.

SALT RIVER RESERVOIR.

BORINGS.

Borings were made to bed rock at 31 points in the canyon, on four different lines. The first trial was made near the upper end of the canyon near the site selected by the Hudson Reservoir Company. Five holes were here drilled to rock, the depth in two of them being 44 and 64.5 feet. These results are shown in fig. 3. Another site was then selected about 1,600 feet downstream, and conditions were so much more favorable that a more thorough exploration was made, and the greatest depth being less than half that found above, the lower site was decided upon. Fig. 4 shows profiles of these borings. Following is a complete list of the borings.

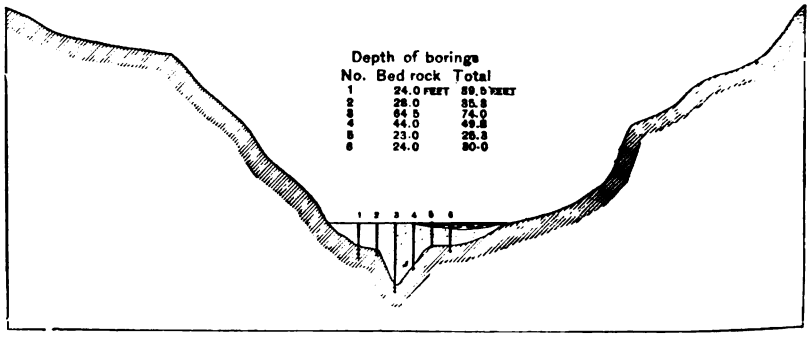
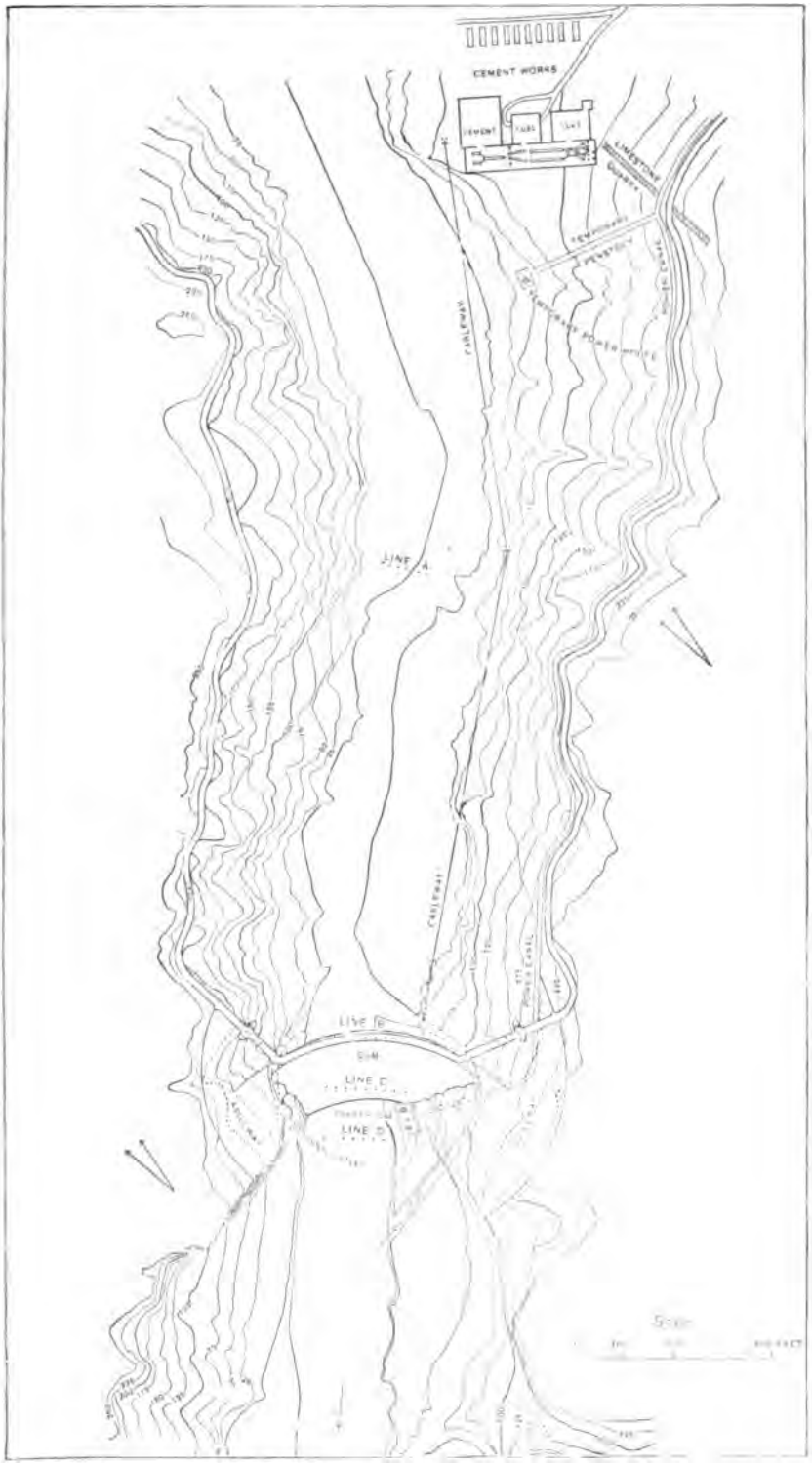


FIG. 3.—Profile of borings at Hudson Reservoir Company's dam site.



PLAN OF DAM, POWER PLANT, AND CEMENT FACTORY.

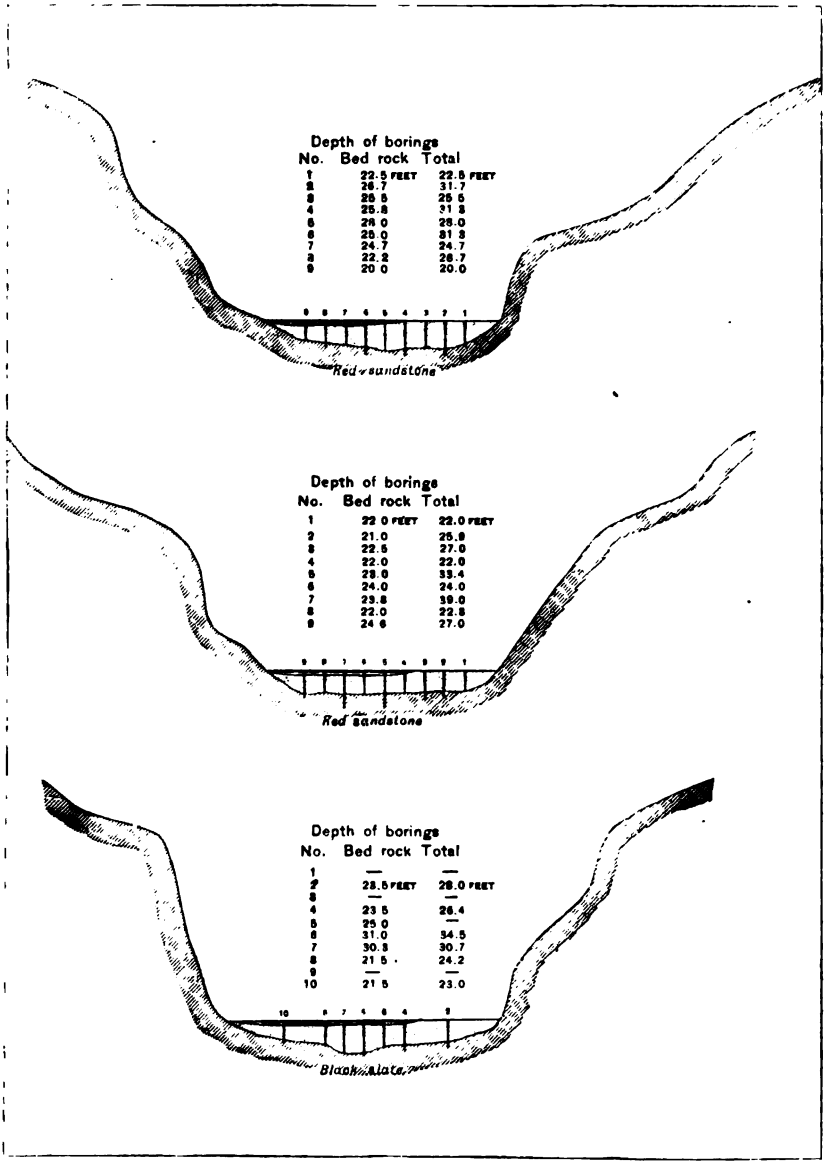


FIG. 4.—Profiles of borings at Salt River dam site.

Borings at Salt River dam site.

No.	Bed rock.	Total depth.	Character of rock.
Line A, Hudson Reservoir Company site.	*Feet.*	*Feet.*	
1	24.0	39.5	Red sandstone.
2	28.0	35.3	Sandstone.
3	64.5	74.0	Coarse, soft white sandstone.
4	44.0	49.8	Broken quartzite.
5	23.0	25.3	Do.
6	24.0	30.0	Do.

Borings at Salt River dam site—Continued.

No.	Bed rock.	Total depth.	Character of rock.
Line B, 1,600 feet below line A.	*Feet.*	*Feet.*	
1	22.5	22.5	Red sandstone.
2	26.7	31.7	Do.
3	25.5	25.5	Do.
4	25.8	31.3	Do.
5	28.0	28.0	Do.
6	25.0	31.3	Do.
7	24.7	24.7	Do.
8	22.2	26.7	Do.
9	20.0	20.0	Do.
Line C, 100 feet below line B.			
1	22.0	22.0	Red sandstone.
2	21.0	25.9	Do.
3	22.5	27.0	Do.
4	22.0	22.0	Do.
5	23.0	33.4	Do.
6	24.0	24.0	Do.
7	23.8	39.0	Do.
8	22.0	22.8	Do.
9	24.6	27.0	Do.
Line D, 100 feet below line C.			
1			
2	23.5	28.0	Black slate.
3			
4	23.5	26.4	Black slate.
5	25.0		Do.
6	31.0	34.5	Do.
7	30.3	30.7	Do.
8	21.5	24.2	Do.
9			Do.
10	21.5	23.0	Do.

CAPACITY OF RESERVOIR.

The capacity of the reservoir was determined by a plane-table survey for each 10-foot contour to a height of 200 feet above the bed of the river in the gorge. These capacities are given in the following table.

Capacity of Salt River reservoir.

Height above low water.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
10	24	120	120
20	128	760	880
30	224	1,760	2,640
40	401	3,125	5,765
50	694	5,475	11,240
60	1,085	8,895	20,135
70	1,458	12,715	32,850
80	2,103	17,805	50,655
90	2,930	25,165	75,820
100	3,682	33,060	108,880
110	4,391	40,365	149,245
120	5,536	49,635	198,880
130	6,394	59,650	258,530
140	7,293	68,435	326,965
150	8,411	78,520	405,485
160	9,664	90,375	495,860
170	10,769	102,165	598,025
180	12,158	114,635	712,660
190	13,459	128,085	840,745
200	14,617	140,380	981,125

It will be noticed that for a dam of a height of less than 100 feet the capacity of the reservoir formed is not extraordinary, but above this height it increases more rapidly, and at a height of 200 feet is nearly a million acre-feet. It would be entirely practicable to construct a reservoir of several times this capacity, but this is not justified by the conditions; the limit to the economical height of dam is determined by the supply of water available for storage.

PLANS FOR THE DAM.

The gorge on Salt River is an especially favorable site for a masonry dam, and the most permanent, conservative, and secure form of high dam that is known to engineering science can be constructed. The formation is sedimentary, with the strata inclined at an angle of about 30° to the horizonal, dipping toward the reservoir, a most favorable condition for retaining stored waters and for the stability of the dam. The foundation and abutment of hard, tough, fine-grained sandstone are all that could be desired. Building stone of the same material is at hand, and above the site. As elsewhere set forth, good Portland cement can be made in the vicinity. Sand for mortar can be obtained from the river bed, but will have to be washed and screened, and it is thought that the best plan will be to manufacture sand by crushing quartzite, which occurs in abundance near the site. This will provide an ideal sand, and as power is abundant its cost will not be great.

The dam must be so designed and constructed as to be safe from destruction by any or all of the forces acting upon it. It is possible for a masonry dam to fail in any one of three ways: 1. By overturning; 2, by sliding on the base, or on any horizontal joint; 3, by crushing its foundation or masonry near the base. A factor of safety of at least two is secured against overturning by so designing the dam that under all conditions the resultant of all the forces acting will fall within the middle third of any horizontal joint. This also eliminates the possibility of any tensile strains in the masonry, a very desirable result. The same condition also secures safety against sliding, which is insured in a still greater degree by constructing the masonry of random rubble, and by the use of hydraulic mortar, bonding it together and to its base, so that it becomes a true monolith—a part of the solid rock to which it is firmly joined. Under these conditions a large margin of safety is provided, as the structure can not slide without shearing the masonry. In addition to these precautions the dam planned is to be built in the form of a circular arch, greatly increasing its safety against both sliding and overturning. In fact, neither can occur without overcoming the gravity and cohesion of the masonry, and also crushing the masonry or abutments. The total factor of safety against failure by the first and second methods can not be exactly known, but it is unquestionably very great. The third

method, that of the crushing of the masonry, is not affected by the curved plan, and there is room for considerable difference of opinion as to what are safe limits of pressure. The best guide, when intelligently followed, is the experience of the past. The following table gives pressures in some existing structures:

Pressures on masonry in existing structures.

Structure.	Material.	Pressure per square foot.	Authority.
		Tons.	
Bridge, Pont-y-Prydd, Wales	Limestone rubble, lime mortar.	20.7	I. O. Baker.
Brooklyn Bridge	Granite masonry	39.5	Duryea & Mayer.
Washington Monument, in wind.	Cut marble	25.4	Col. T. L. Casey.
St. Louis Bridge, before completion.	Cut limestone	38.0	History St. Louis Bridge, p. 370.
South Street Bridge, Philadelphia.	do	15.7	Trans. Am. Soc. C. E., Vol. VII, p. 305.
Rookery Building, Chicago	Cut granite	30.0	I. O. Baker.
Bear Valley dam	Granite rubble	40.0	J. D. Schuyler.
All Saints' Church, Angers	Forneaux stone	43.0	J. T. Fanning, p. 403.
Chapter House, Elgin	Red sandstone	20.0	Do.
St. Paul's, London	Portland limestone	19.7	Do.
St. Peter's, Rome	Calcareous tufa	16.7	Do.
Various arch bridges	Cut masonry	60.0	Do.
Quaker Bridge dam (projected).	Rubble masonry	15.0	Rep. Aqueduct Com., p. 55.
Almanza dam (300 years old)	do	14.3	Edward Wegman, p. 24.

Various experimental tests.

Material crushed.	Pressure per square foot.	Authority.
	Tons.	
Concrete prisms cut from Vrynwy dam	181	Sir Andrew Clark.
Granite ashlar, with mortar 1:2	583	Austrian Society E. & A.
Sandstone rubble, mortar 1:2	255	Do.
Sandstone rubble, mortar 1:3½	184	Do.
Gravel concrete 1:2:3	128	Do.
Gravel concrete 1:3:5	66	Do.

Two cubes of 1 cubic inch each were cut from briquets of neat cement, manufactured from materials obtained near the site. These were tested at the United States Navy-Yard, in Washington.

Sample No. 1 crushed at 6,690 pounds, or 482 tons per square foot.

Sample No. 2 crushed at 8,840 pounds, or 636 tons per square foot.

Two cubes with edges of 2 inches were cut from samples of the rock to be used in Salt River dam, and crushed in the testing machine at the United States Navy-Yard, in Washington.

Sample No. 1 crushed at 59,650 pounds, being 14,912 pounds per square inch, or 1,074 tons per square foot.

Sample No. 2 crushed at 100,000 pounds, this being 1,800 tons per square foot. These results are so high that the strength of the rock is entirely eliminated from the discussion.

Test No. 4, in the above table, made by the Austrian Society, is very nearly representative of the masonry to be used in the proposed

Salt River dam. A coefficient of safety of 10 in such masonry would permit of pressures of over 25 tons per square foot. As will appear later, the maximum pressures permitted in the proposed dam will be far below this figure.

The recorded failures of high masonry dams are as follows:

At the Habra dam in Algiers poor hydraulic lime was used, and a red earth with a large percentage of clay was used in the mortar instead of sand. This combination made a poor mortar, and the rock was also poor, both in the masonry and the foundation, being a calcareous grit of varying quality, and all porous. It is supposed that the failure occurred by the crushing of the foundation under a computed stress of 13.3 tons per square foot.

At the Bouzy dam in France the foundation was fissured and permeable and not on solid rock, allowing an immense upward hydrostatic pressure; the section was so light as to permit great tension in the masonry in the back. It was straight in plan, and when the reservoir was nearly filled the central portion of the wall was shoved forward about a foot, causing ruptures and leakage. This was afterwards repaired and the foundation reenforced. Six years later, when the reservoir was full, the dam suddenly overturned at a plane about 33 feet below the top. The above-recited defects were the undoubted cause.

At the Puentes dam in Spain the central portion of the dam was founded upon piles driven in earth. When the rising water applied a heavy hydrostatic pressure, this portion of the foundation suddenly gave way and left the top and ends of the dam standing in the form of an arched bridge.

The dam at Austin, Tex., was an overflow dam built of limestone rubble, the stone being very soft and of poor quality. The foundation was on a geological fault, and was of soft limestone, in thin, horizontal layers, which had little adhesion, and probably very little friction upon one another, and the failure, which was by sliding, is supposed to be due to this fact.

In all four of the above cases the foundation was defective. In three the stone was poor and in two the mortar was poor. All were straight in plan except the Puentes, which was polygonal in plan and arched upstream. This dam seems to have been very well planned and constructed, except for the one fatal defect of being founded on piles instead of solid rock.

All of the defects in these failures can easily be avoided in the proposed dam by a reasonable application of care and skill.

The proposed dam is designed to be 217 feet above low water in the river at the dam site and to store water at a maximum depth of 190 feet, the total height of dam above lowest foundation being about 247 feet. Spillways 20 feet deep will be excavated in the solid rock sides of the canyon and the rock used in the construction of the dam. The location lends itself admirably to a curved form of dam, this form

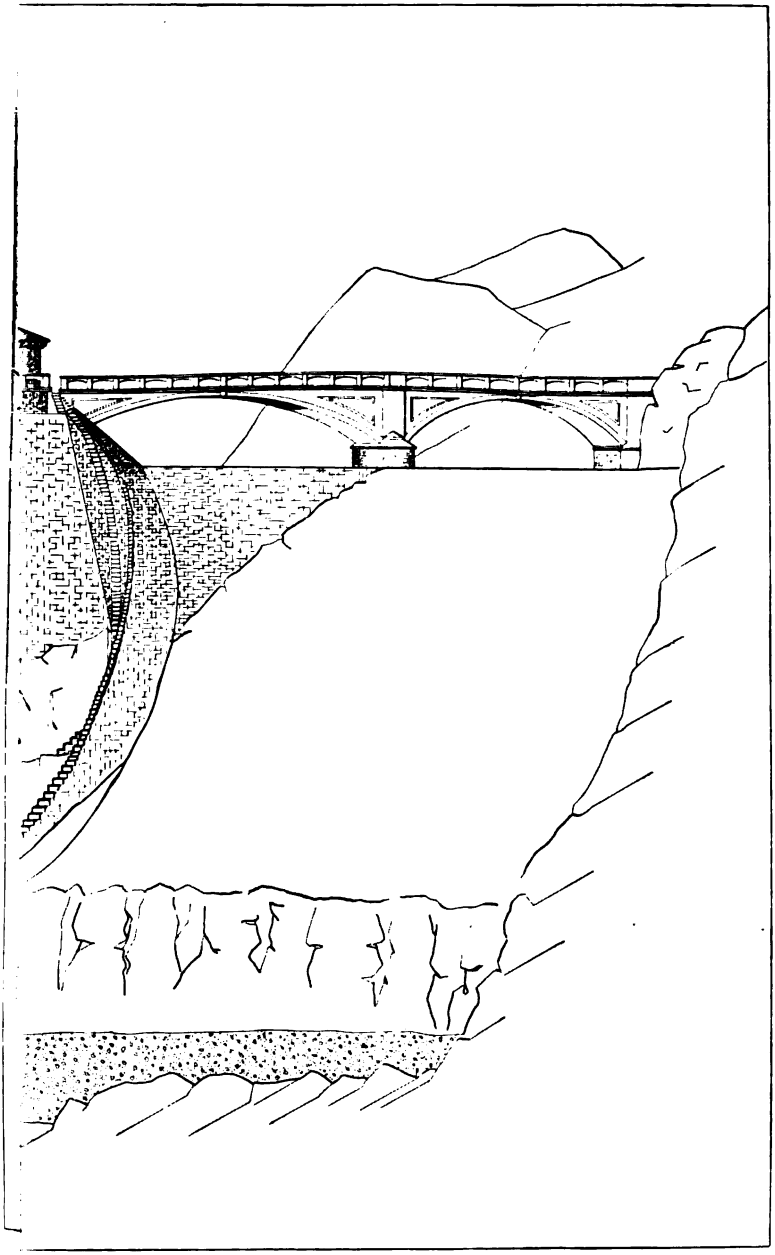
containing but little more ma .rial than a straight one of the sam section. The proposed structure is to be built on a circular curv convex upstream, the back having a radius of 400 feet and the face shorter radius from the same center. The dam is to be of uncourse rubble masonry and to have a section on modern conservative idea as a simple gravity structure, and the added stability due to its curve form will greatly increase its factor of safety. The rock of which th dam will be constructed will be excavated from the spillways, and i a tough, close-grained sandstone. A sample was taken from each sid of the canyon and tested for specific gravity in the laboratory of th United States Geological Survey. The following are the results o this test:

Specific gravities of two specimens of sandstone.

I. Determined on lumps.
  A. In ordinary distilled water as quickly as possible.
    No. 1.—Specific gravity, 2.42 at room temperature.
    No. 2.—Specific gravity, 2.47 at room temperature.
  B. After soaking in distilled water 24 hours.
    No. 1.—Specific gravity, 2.44 at room temperature.
    No. 2.—Specific gravity, 2.49 at room temperature.
  C. After standing in distilled water under the air pump for 24 hours.
    No. 1.—Specific gravity, 2.50 at room temperature.
    No. 2.—Specific gravity, 2.52 at room temperature.
II. Determined on the powdered samples.
    No. 1.—Specific gravity, 2.583 at 21.5 C., compared with water o same temperature.
    No. 2.—Specific gravity, 2.611 at 17.5 C., compared with water o same temperature.

Tests for crushing were also made and are given on page 36.

The rock is to be used in as large pieces as practicable, in order t make the number of joints as few and the quantity of mortar as smal as may be. It is estimated that the rock will occupy 70 per cent o the structure. Fifteen per cent will consist of cement mortar, i which the stones are bedded, and 15 per cent will consist of cemen concrete rammed into the vertical joints. Taking the weight of th mortar as 115 pounds per cubic foot and that of the concrete as 13 pounds, the masonry will weigh, as nearly as can be estimated, 14 pounds to the cubic foot. On this estimate the strains have bee computed and the section of the dam designed. As the dam is t serve as a highway, a top width of 16 feet has been adopted, wit parapets along the sides. The section adopted is the smallest consistent with the necessary top width, and with the requirement that th resultants of all forces acting upon the dam shall be at all time within the middle third. The pressure on the toe when the reservoi is full will be 15.9 tons per square foot, computed on the assumptio that the dam is a rigid monolith and nonelastic. Any elasticity i may have will tend to relieve this pressure. The maximum possibl pressure, 16.64 tons, occurs at the heel when the reservoir is empty, with a strong wind blowing upstream.



The table on p. 36 shows fourteen instances with pressures greater, some of them many times greater, than those in the proposed dam.

The following specifications are proposed for the dam:

SPECIFICATIONS FOR THE CONSTRUCTION OF THE DAM.

Diversion of the river.—The diversion of the river will be accomplished by means of sheet piling driven as deeply as practicable directly across the canyon, beginning at the south side and reaching as nearly as practicable to bed rock, the piling to be reenforced at and above the surface by a heavy wall of sand and gravel excavated from the site of the dam, the water to be diverted through the outlet tunnel, which will be constructed in advance. The gravel wall will be built at least 1 foot higher than the top of the outlet channel for three-fourths of its length, about 50 feet of the southern end of the embankment being left at an elevation 6 feet lower, to be utilized as a spillway for excessive floods which may occur too large for the capacity of the outlet tunnel. The excavation for foundation will begin at the southern wall of the canyon, and as rapidly as completed to solid foundation will be filled with masonry. As soon as 40 or 50 feet of the southern end of the foundation is completed, a wooden flume will be placed at the above-mentioned spillway on the embankment, reaching downstream over the completed portion of the foundation, discharging into the stream bed at least 300 feet downstream from the toe of the dam. This flume will be about 1,000 feet long, and in that distance will have a fall of nearly 8 feet, which will give it a high velocity and enable it to discharge any floods likely to occur. The pumps employed in drying the foundation excavations will discharge into this flume.

In case sheet piling can not be driven deep enough to cut off the underflow, pipes shall be driven along the line across the canyon and cement grout pumped in until the desired result is obtained.

Foundation.—All earth, sand, gravel, bowlders, disintegrated, loose, and seamed rock will be excavated and removed from the entire area of the base of the dam in order to secure a firm foundation on solid rock. Explosives shall not be used in excavating the rock unless absolutely necessary, and when used shall be only in small quantities and in shallow holes to avoid fracture of the rock forming the foundation of the dam. The entire foundation shall be thoroughly washed with wire brooms, first with water and then with thin cement grout. Throughout the length of the foundations a trench 6 feet wide and 6 feet deep, 15 feet from the heel of the dam and parallel thereto, shall be cut in the solid rock of the foundation.

Masonry.—The main body of the dam shall be constructed of broken range cyclopean rubble. The stone shall be quarried from the walls on each side of the canyon, shown in the drawing as proposed spillways. If a sufficient quantity of hard, fine-grained stone can not be obtained in these spillways it shall be quarried elsewhere.

All stone shall be thoroughly washed and laid in Portland cement mortar, and each stone shall be laid on its largest bed. The stone for the upstream face shall be rough pointed, so as to lay with horizontal beds and vertical joints. No mortar joint in the face shall exceed 1 inch in thickness. At least one-fourth of the area in the face must be headers evenly distributed throughout the wall, and every header shall be laid over a stretcher of the underlying course. The stone shall be so arranged as to form a proper bond, in no case less than 1 foot, with the stone of the underlying course. The stretchers must not be less than 3 feet long, nor less than 2 feet in any other dimension. The headers must not be less than 6 feet in length nor less than 2 feet in any other dimension.

The body of the dam shall be composed of as large stone as practicable, well shaped, and laid so as to break joints and thoroughly bond the work in all directions. Each stone shall be laid on its largest face in a bed of Portland cement mortar of the quality hereafter specified. Vertical joints between the stones in the body of the dam must be nowhere less than 4 inches and must be carefully and thoroughly filled with Portland cement concrete, which shall be rammed into place by hand. To secure thorough bedding each stone must be lifted and the bed examined, to the end that all space in the dam not occupied by stone shall be absolutely filled with mortar, so as to make a water-tight construction. The masonry shall be kept wet during the time of construction. The aim shall be to use the largest proportion of stone and the smallest proportion of mortar and concrete in the dam that can be practicably secured. To this end facilities shall be provided for handling stones weighing 12 tons, and large stones shall be used as far as practicable. To the same end the stones shall be split from the large masses found in the quarry by the "plug-and-feather" method, or any similar process that may be found efficient in breaking the stones along regular lines, so that joints to be filled with mortar may be reasonably thin and uniform.

Mortar and concrete.—All mortar used in the lower 30 feet of the dam shall consist of 1 part of Portland cement, 2 parts of good sharp sand; and all concrete used in this portion of the dam shall consist of 1 part cement, 2 parts sand, and 3 parts of broken stone graded to such size as will pass through a screen with meshes 2 inches square. The mortar and concrete used in the upstream face of the dam for a thickness of 20 feet shall be of the quality above specified.

In all parts of the dam which are more than 20 feet from the upstream face and 30 feet from the base the mortar shall be 1 part Portland cement to 3 parts of sand, and concrete of 1 part Portland cement, 3 parts sand, and 4 parts broken stone of a size to pass through a screen with meshes 2 inches square. All mortar and concrete shall be thoroughly mixed as the work progresses and used so promptly that there will be no danger whatever of incipient setting of the cement pr

vious to the completion of the masonry in which it is placed. No cement shall be used until at least sixty days after its manufacture, and not until it shall show satisfactory tests according to the chemical and physical requirements adopted by the American Society of Civil Engineers.

The reason for using a larger percentage of cement in the base of the dam is that here will be the greatest pressures, and the higher percentage of cement will give a greater power of resistance to crushing. The high percentage of cement is maintained on the water face of the dam, all the way to the top, in order to render it as nearly impervious as possible.

It may be confidently predicted that a masonry dam at the proposed site, constructed on the above plans and specifications, would be absolutely permanent, "safe, solid, and secure for all ages to come," as truly as the "everlasting hills," of which it will become an integral part.

SEDIMENT.

Most of the streams of the southwest carry a considerable quantity of solid matter which causes annoyance in canals, and has a tendency to fill any reservoir constructed on the stream. This is true of the Rio Grande, Colorado, Pecos, and Gila rivers. There is silt also in the waters of Salt River, as shown by its occurrence in the canals, but it is not nearly as abundant as in the streams above mentioned. The basin tributary to the Salt River reservoir lies in large part in high timbered country, and includes the Apache Indian Reservation. These Indians constitute probably the most efficient forest patrol in the country, and their reservation is almost entirely covered with forest and grass. The basin of Tonto Creek, and a few other tributaries, however, are closely pastured and deliver some silt during sudden floods.

Observations of the amount of sediment carried give the results found in the following table:

Percentage of sediment found in Salt River water.

Date.	Sediment.	Total volume.
1901.	*Per cent.*	*Acre-feet.*
January	0.00026	9.27
February 1-15	.00053	34.42
February 16-28	.00012	8.28
March	.000099	9.53
April 1-18	.0000021	.06
April 19 to May 26	No sediment.	.00
May 27-31	.005895	28.74
June	No sediment.	.00
July	.003924	83.58
August	.004128	134.16
September	.0013323	23.85
October	.000054	5.04
November	.000058	.65
December	No sediment.	.00
Total for the year		337.58

NOTE.—From January 1 to April 18, 1901, observations were made at McDowell station; balance of the year at reservoir site.

The above table shows that during the period covered by the o vations the sediment carried was very small in amount, almost ne ble, but the discharge during the year was far below the normal it is believed that the proportion of sediment shown by the obs tions was also below the normal. If we take 1,000 acre-feet a average inflow of sediment, this will be nearly three times observed during 1901, and yet it would require eight hundred ye fill the reservoir if none were drawn off. It would probably b hundred years before the loss of storage capacity would be seri felt and it would become necessary to resort to methods of clear out.

At all times when the river is in flood the water in the rese will be more or less turbid. The lower the stage of the reservoi the greater the flood in the river the greater will be the percenta sediment held in suspension. The greatest amount of sediment usually be found in the lower layers of water, and it will t fore contribute to the maintenance of the storage capacity to all waters from the lowest possible point at all times. Two ou are provided in the form of tunnels 10 by 13 feet, one around end of the dam. It should be made an invariable rule that when water begins to run over the spillway the gates must be opene full capacity, not only to draw off the maximum quantity of s ment but also to reinforce the spillway capacity as much as possi

Experience at the Sweetwater and other reservoirs shows that greatest deposits of sediment are in the deepest part of the reserv which in this case is near the dam. The above provision would pose of a considerable portion of this, and any further provision removing silt would be unnecessary for more than a century.

SPILLWAY PROVISION.

The greatest flood ever known in Salt River Valley occurred in F ruary, 1891. It is described in the Twelfth Annual Report of t United States Geological Survey, and has been referred to on page of this report. The maximum discharge of this flood was estimat at the almost incredible volume of 300,000 cubic feet per second. freshet of less magnitude, but still very large, occurred in 1890. The is abundant evidence that there had been no flood approaching the in magnitude for a very long time. The drainage area from whi this flood was drawn was considerably more than double the area trib tary to the proposed Salt River reservoir, but the latter having mo than the average precipitation, it is credited with 54 per cent of t total discharge under the discussion of "Water-supply" on page 2 A smaller drainage basin is, moreover, liable to a relatively high flood discharge than a larger one, though the floods are of short duration. From the above considerations it is estimated that t maximum flood wave possible at Salt River reservoir is 220,000 cub

feet per second, reaching this amount by a rapid increase in volume, and declining somewhat less suddenly from the maximum to the normal discharge. On this assumption an examination has been made of the effect of such a flood upon the reservoir. It is assumed that the reservoir is full up to the bottom of the spillway, and that a great flood occurs, with a mean discharge for the first hour of 120,000 cubic feet per second, and increases its discharge 10,000 cubic feet per second during each hour for eleven hours, at the end of which time it has reached its maximum wave of 220,000 cubic feet per second. The discharge then decreases in an arithmetical progression for twenty hours, at the rate of 5,000 second-feet per hour, reaching a discharge of 120,000 second feet as a mean for the thirty-first hour.

This spillway as planned has a total length of 350 feet, and its bottom is 27 feet below the top of the dam. Its discharge capacity is computed from the formula $Q=H^{\frac{3}{2}}\ 1220=3.5\ LH^{\frac{3}{2}}$.

Effect of maximum flood on Salt River reservoir, with spillway 350 feet long, 190 feet above river bed.

[$Q=H^{\frac{3}{2}}\ 1220$.]

Hour.	Inflow.		Outflow.		Net rise.	Elevation.
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.		
					Feet.	*Feet.*
1	120,000	9,920	12,920	1,065	0.82	190.82
2	130,000	10,740	14,380	1,185	.87	191.69
3	140,000	11,570	16,560	1,365	.92	192.61
4	150,000	12,390	19,430	1,600	.97	193.58
5	160,000	13,320	22,920	1,890	1.01	194.59
6	170,000	14,040	27,190	2,245	1.03	195.62
7	180,000	14,870	31,600	2,610	1.06	196.68
8	190,000	15,690	36,730	3,035	1.08	197.76
9	200,000	16,520	42,360	3,500	1.10	198.86
10	210,000	17,350	48,460	4,000	1.11	199.97
11	220,000	18,170	54,980	4,540	1.12	201.09
12	215,000	17,760	61,590	5,085	1.03	202.12
13	210,000	17,350	67,940	5,610	.94	203.06
14	205,000	16,930	73,960	6,110	.86	203.92
15	200,000	16,520	79,620	6,575	.78	204.70
16	195,000	16,170	84,900	7,010	.71	205.41
17	190,000	15,690	89,790	7,415	.64	206.05
18	185,000	15,280	94,270	7,785	.57	206.62
19	180,000	14,870	98,340	8,120	.51	207.13
20	175,000	14,450	102,740	8,485	.45	207.58
21	170,000	14,040	105,300	8,695	.40	207.98
22	165,000	13,630	108,200	8,935	.35	208.33
23	160,000	13,220	110,810	9,150	.30	208.63
24	155,000	12,830	113,040	9,335	.26	208.89
25	150,000	12,390	114,920	9,490	.21	209.10
26	145,000	11,980	116,460	9,620	.17	209.27
27	140,000	11,570	117,630	9,720	.13	209.40
28	135,000	11,150	118,610	9,795	.10	209.50
29	130,000	10,740	119,250	9,850	.06	209.56
30	125,000	10,320	119,620	9,880	.03	209.59
31	120,000	9,920	119,760	9,892	.00	209.59
Capacity of spillway			123,120	10,170		210.00

At the end of the thirty-first hour the surface of the water has reached an elevation of 209.6 feet, or 7.4 feet below the top of the dam, and from that point begins to decline, the spillway having at this elevation a discharge of 119,760 cubic feet per second. The above-assumed flood wave might, therefore, be considerably exceeded

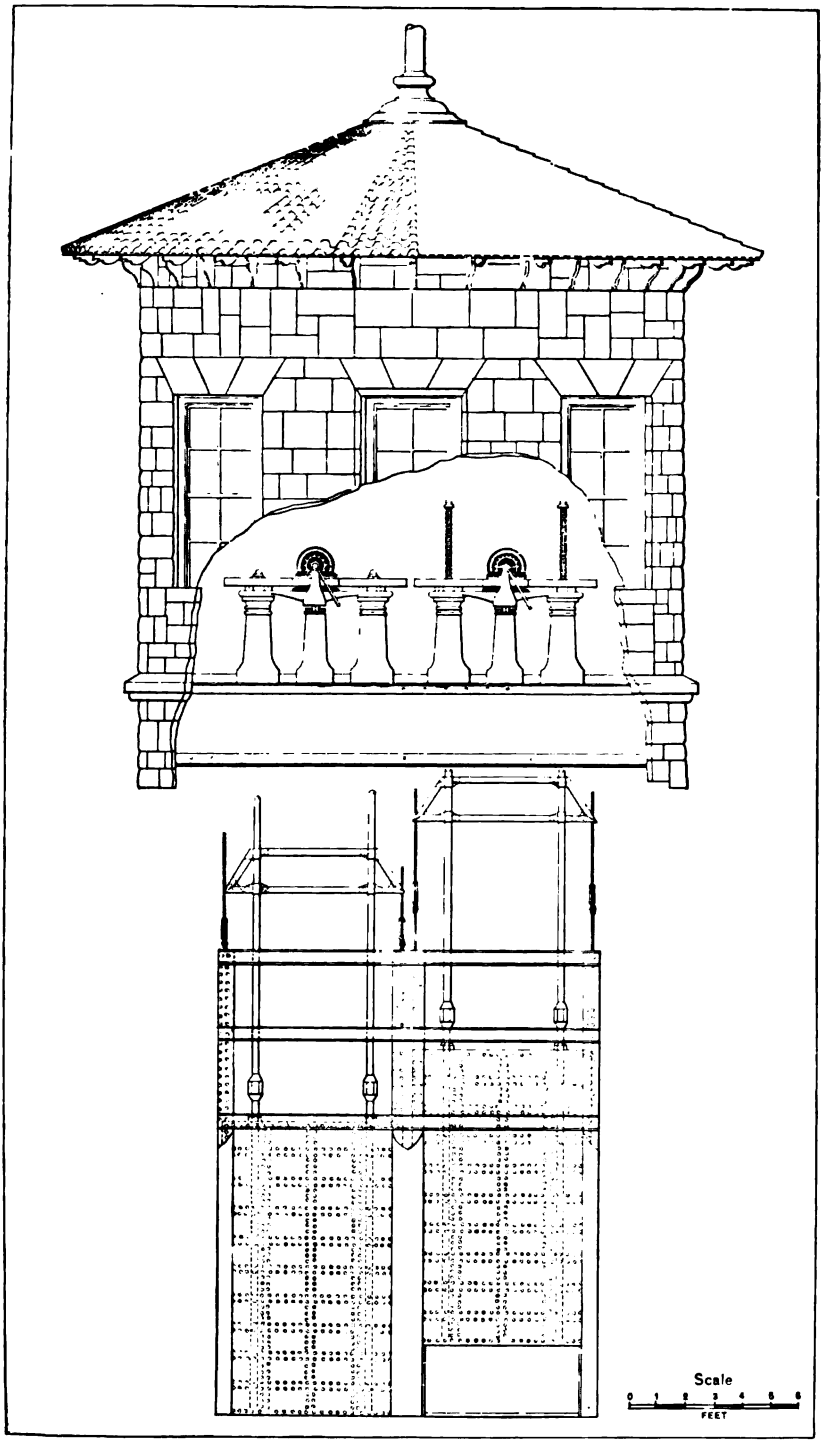
without flowing over the dam, and therefore the spillway provisions as planned are considered ample for all possible requirements. It should be noted, however, that the dam would not be injured nor endangered by a very considerable flow over the top.

OUTLET WORKS.

For the purpose of facilitating the discharge of sediment from the reservoir, and also to furnish the maximum reenforcement to the spillways, it has been decided to draw all water from the reservoir through large openings directly on the bottom. Accordingly the plan adopted is to have two tunnels dug through the solid rock, one on each side of the canyon. Each tunnel will be provided with two gates, each 6 feet by 10 feet 3½ inches, with a clear opening of 5 feet 4½ inches by 10 feet, making a total area of 215 square feet clear opening. This would have a discharge capacity of about 1,500 cubic feet per second with water standing in the reservoir on a level with the top of the tunnels. When the reservoir stands higher than this the head would, of course, increase the possible discharge, and when water begins to flow through the spillways the tunnel would have a discharge capacity of about 12,000 cubic feet per second, and with the spillways running full, about 14,000 cubic feet per second. The head on the lower sill of the outlet tunnels would be 190 feet with water standing at the level of the bottom of the spillways. This will be the maximum head frequently encountered, but the possible head would be 20 feet more, or 210 feet, with water flowing over the spillways 20 feet deep, which is considered the maximum head possible, encountered only at long intervals, if ever. This will produce a mean pressure of about 12,800 pounds per square foot on the gates, or a total on each gate of about 390 tons. These pressures and sizes require gates of great strength and efficient means of controlling their position.

Each gate is built of nine parallel 9-inch I beams, two channels horizontally, and three longitudinal beams, the whole inclosed by a half-inch plate solidly riveted to the beams and channels, so as to make the entire gate act as a girder. It will be the aim to make this girder water-tight on the edges and the side exposed to the water, but drainage holes will be provided on the lower side to discharge any chance leakage.

The pillar which will occupy the center of each tunnel is built of plates and angles in the form of a large I beam, and is reenforced on each side by a 12-inch I beam, and the whole is inclosed by a thin steel skin, to minimize the tendency to produce vibrations. The beams are so arranged as to diminish the contractions also, and thus increase the discharge. The sheet steel will be continued along the sides and bottom of the tunnel throughout its entire length. Under



ELEVATION OF TOWER, GATES, AND GATE LIFTS.

these arrangements the velocity of the water through the tunnel, running full, with the water in the reservoir at the level of the top of the tunnel, will be about 7 feet per second, and will increase to over 60 feet per second with the water 20 feet deep over the spillways. Each gate will be worked by two hollow rods running upward through the shaft and tower to the tower houses at the top of the dam, where they will be worked by screws operated by electric motors.

The hollow rods will consist of 3-inch, double-extra heavy steel drivepipe, and will work in guides, as shown in Pl. XXI. The upper section of rod which carries the thread for moving the gates will be solid.

The bearings for the gates will be upon solid steel rollers placed to eliminate friction. A general view is shown on Pl. XXII.

The steel is estimated at 8 cents per pound erected.

POWER PLANT.

In the construction of a great dam one of the most important elements is that of power. This is necessary on a large scale for drilling purposes, for handling rock, for mixing and handling mortar, and for crushing rock to be used in concrete. In the present case, furthermore, it has been found possible and very desirable to manufacture on the ground the large quantity of cement required in the dam. This would require about 300 horsepower day and night, for grinding rock and clinker, and for handling materials and running machinery. It is usual to provide such power by means of steam engines, but in the present case this is rendered very expensive by the scarcity of fuel. Coal, in quantities, now costs $10 per ton in Globe, and the wagon haul to the dam site would nearly double this. A limited amount of wood is available, but to secure the large quantity which would be required if it were the sole dependence for power would involve a long haul.

The best means for providing the necessary power is by the development of water power on the river. This will involve the construction of a diversion dam and canal, which can afterwards be utilized, if required, for sluicing accumulated silt out of the reservoir. The power developed can afterwards be used in the neighboring mines or transmitted to the valley below for pumping purposes. For either purpose it will be a valuable asset.

The standard canal section adopted has a bottom width of 8 feet, water depth of 3.5 feet, total depth of 4.5 feet, with side slopes of 1 to 1 in excavation and 1½ to 1 in embankment. Its slope will be 0.0006.

In the first 12,000 feet of the line the depth will be slightly increased to provide for seepage losses. Small drainage lines will be crossed by means of concrete culverts. Flume construction will be employed only where absolutely necessary, on account of its lack of perma-

nence. The adopted flume section is a rectangular box, 4 feet deep and 7 feet 8 inches wide inside, built of 2-inch redwood plank, supported by frame of native pine. Sawmills will be established near the line and logs floated down Salt River from the mountain valleys above. This native timber will also be used for false works and other temporary structures about the works. The details of flume construction are shown on Pl. XXIII.

There are to be two tunnels on the line, one 15,000 and one 18,000 feet in length. Both are to be in coarse gravel, and will be lined with concrete.

No detailed surveys have been made of the line, and the estimates which follow should be regarded as only approximate. The estimated cost of earth excavation is 15 cents per cubic yard, and of rock $1 per cubic yard.

The proposed canal would head some distance above the reservoir, follow above its water line, and finally discharge just below the dam, with an available head of about 180 feet. It is designed to deliver 100 cubic feet per second, and to develop a net energy of about 1,200 horsepower after deducting seepage, friction, and losses in water wheels, electric plant, etc. It is designed to use 900 horsepower at the dam and 300 horsepower at the cement mill.

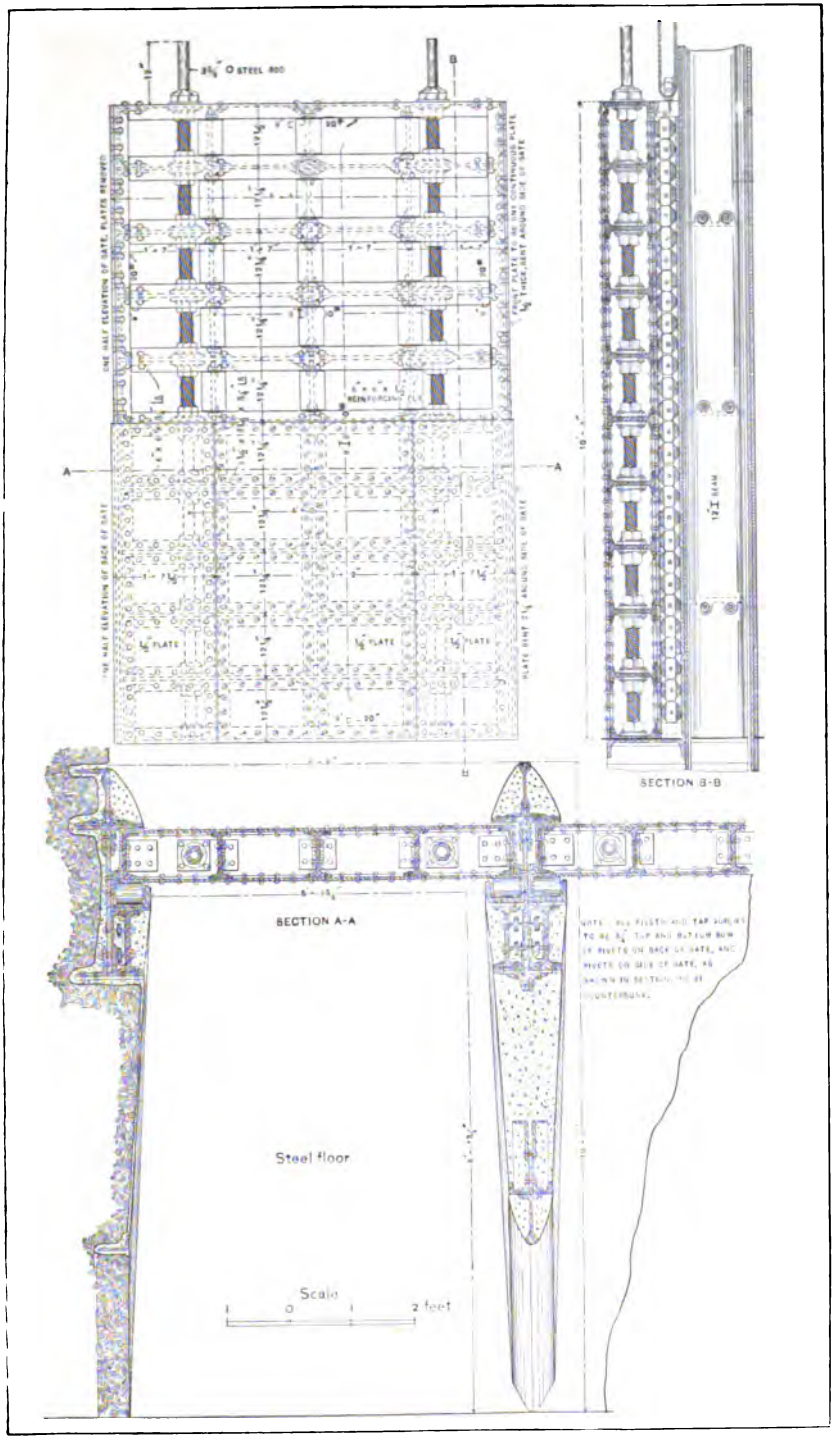
The power plant will consist of three units of 300 kilowatts each, one of which will be temporarily installed near the cement mill, to be used there in making cement and in drilling for the outlet tunnels, dam foundations, etc., before the permanent plant is installed, until it is desired to store water above the 25-foot contour of the reservoir, at which time the manufacture of cement should have been completed, when this unit will be placed alongside the other two below the dam. The two units placed below the dam will be at first protected by a temporary power house, until the foundation of the dam at that point is brought up to the level of the ground, when the stone power house will be built.

The windows of the power house will be 10 feet above the bed of the river, and the tailrace of the power house will be provided with a gate by which, if it ever becomes necessary, backwater from the discharge of the spillways can be prevented from entering the power house. At such times, perhaps once in twenty or thirty years, it may become necessary to close down the power plant for a few hours.

The following approximate estimate of the cost of the power installation has been prepared:

Estimated cost of power plant.

Diversion works:		
Dam	$10,000	
1,000 feet of flume	2,325	
75,200 feet of canal	58,975	
3,300 feet of tunnel, at $6	19,800	
		$91,100



ELEVATION AND SECTION OF OUTLET GATES.

Water wheels, etc.:		
9 wheels, shafts, nozzles, housings, etc	$7,350	
3 pairs couplings for attaching dynamos	555	
270 feet 52-inch pipe for penstock	1,600	
Receiver and 9 branches	1,555	
Freight on 140,000 pounds, at 3 cents	4,200	
Power house	10,000	
		$25,260
Electric plant:		
3 300-kilowatt dynamos and exciters	24,000	
Transformers and motors	35,000	
Transmission lines	1,000	
Freight and installation	12,000	
		72,000
Total cost of power plant		188,360

The power plant as planned is about what is necessary in the construction of the dam and the manufacture of cement. It contemplates the use of the entire flow of the Salt River at minimum stages, and hence is the maximum that can be made available at full head for use at all times. After the construction of the reservoir this power can be utilized for other purposes, but if constantly required will consume water from the reservoir during the winter months, when usually a sufficient supply for irrigation purposes can be obtained from the unregulated flow of the Verde River. If, however, the power is used exclusively for pumping water for irrigation, it will not be required during the season of high water on the Verde. When this supply becomes insufficient, it will be necessary to start the pumping plants and to draw water from the reservoir, which can be utilized at such times, both for power and irrigation; hence, if used exclusively for pumping, none will be wasted.

There are other power possibilities in this reservoir site by arranging to draw all irrigation water from the reservoir under a considerable head through turbines which can be used to develop power for pumping purposes. Such development, however, will be of a very different character from the works already planned. The water will be drawn under a variable head, and at times of extreme scarcity, when the reservoir may run nearly or quite empty, and when irrigation water is most needed, the head will be diminished and the water to be drawn will be insufficient or entirely lacking at times when the power for pumping is most needed, unless the duty of the reservoir is diminished to a sufficient extent to prevent this. It is probable, however, that such a utilization of the power could be profitably made. A decision on this point rests on the equation between the cost of necessary plant and the value of necessary storage capacity on the one side as against the value of the water pumped on the other side. There is, however, a limit to the availability of underground waters which can not be definitely known until an extensive trial is made by pumping on the large reservoir of water which seems to be stored

underground in Salt River Valley. The problem, however, is an attractive one, and deserves extensive study in connection with the utilization of Salt River reservoir.

CEMENT MANUFACTURE.

The natural topographic conditions of this site are very favorable for the construction of a masonry dam of the most conservative and permanent design yet devised. This form of construction, however, is rendered very expensive by the remoteness and difficulty of access to the site. There is a wagon haul of over 40 miles across mountainous country from the end of the railroad, which is a branch road with light traffic and high rates. It is estimated that cement would cost at the dam site about $9 per barrel. As over 100,000 barrels of cement would be required for the dam, such a price is a most serious handicap to the project, and presents a strong temptation to adopt a rock-fill type of structure which would be immensely cheaper. However, before deciding this important point, it was thought best to investigate the possibility of manufacturing cement in the vicinity, and, with this object, search was made in Tonto Basin for materials suitable for the purpose. Eight samples of rock and clay were sent in for analysis to E. A. Duryee, superintendent of the cement works at Colton, Cal. The analyses were as follows:

Analyses of rocks and clays from Tonto dam site.

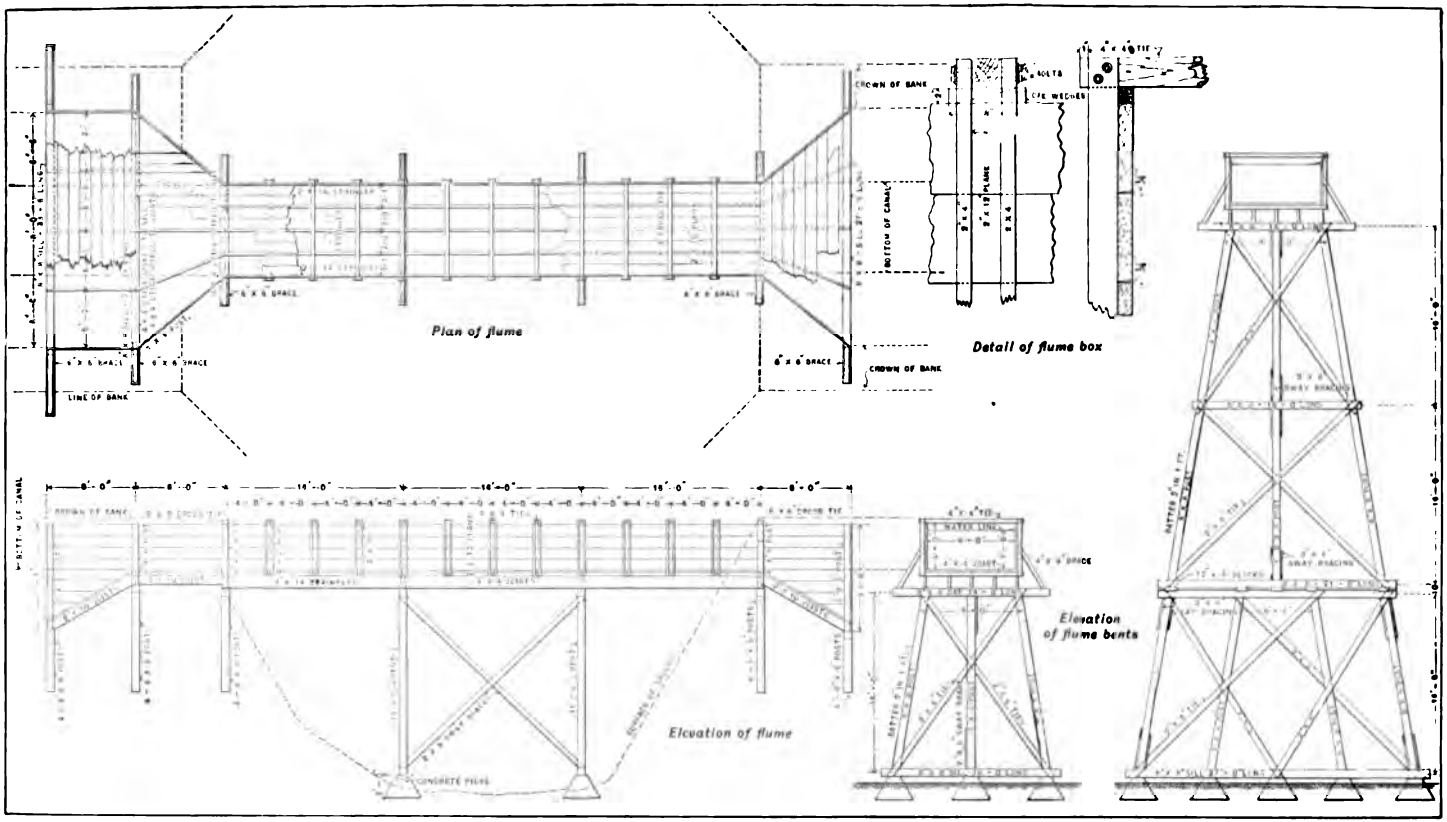
Constituent.	No. 1.	No. 2.	No. 4.	No. 6.	No. 7.	No. 8.
Moisture	.....	2.80	11.25	20.10	13.40	.....
Silica	.....	50.60	55.70	51.00	51.90	67.90
Alumina and ferric oxide	0.20	15.80	20.50	16.70	23.70	18.00
Magnesia	.60	4.072	.....	4.576	.97	.972
Calcium carbonate	95.80	16.60	11.80	6.048	10.90	.00
Insoluble residue	3.30	.....	.....	.....	.....	.....
Total	99.90	89.872	99.25	98.424	100.87	86.872

No. 1. Limestone near dam site; very abundant and convenient.
No. 2. Calcareous shale near dam site; ledge 1 foot thick; expensive to quarry.
No. 3. Shale near dam site; ledge 4 inches thick; expensive to quarry.
No. 4. Clay 1 mile from dam site; abundant.
No. 5. Shale near dam site; ledge 3 inches thick; expensive to quarry.
No. 6. Clay from Sallie May Canyon, 8 miles from dam site.
No. 7. Clay from hills, 3 miles north of dam site; very abundant.
No. 8. Shale from canyon below dam site; ledge 2 feet thick.

The shales, and especially samples 3 and 5, being expensive to quarry and grind, were intended for use only in case the clays should, upon analysis, prove to be unsuitable for the purpose intended.

Everything considered, samples 1 and 7 appeared to be the most favorable for the purpose, and accordingly a quantity of No. 7 and No. 1 were shipped to Colton for an experimental burn. The following is quoted from Mr. Duryee's report:

The clay and limestone were ground separately and then mixed in the proportions of 6.18 pounds limestone and 2.25 pounds clay, making a raw mixture that



DETAILS OF FLUME CONSTRUCTION.

tested 43 per cent lime. As the limestone was very hard and therefore more difficult to make into cement than a softer material, fluorspar to the amount of 1¼ ounces, or 1 per cent, was added. The materials were also ground quite fine, but no finer than is the practice in some cement works, viz:

	Per cent.
Passed a sieve of 50 meshes to the linear inch	99.9
Passed a sieve of 100 meshes to the linear inch	99.75
Passed a sieve of 200 meshes to the linear inch	71.75

The raw mixture was made into briquets, and these, after being dried, were burned in a gasoline furnace. They burned to a good hard clinker of a good color, which yielded a cement of good color.

Analysis of the cement.

Lime	63.56
Alumina and ferric oxide	10.40
Silica	22.85
Magnesia	.71

Alkalies not determined.

Tensile tests of the neat cement briquets.

	Pounds per square inch.
7 days (1 day in air, 6 in water)	410
14 days (1 day in air, then in water till broken)	690
28 days (1 day in air, then in water till broken)	775

Chemical analyses of Nos. 1 and 7 were also made in the laboratory of the Geological Survey, to test the uniformity of the deposits. These samples differ slightly from the samples sent to Mr. Duryee, but still are eminently suitable for the purpose. The following are the results found in the Survey laboratory:

Analysis of limestone from Salt River, Arizona.

CaO	55.56
MgO	.10
Fe_2O_3 and Al_2O_3	.20
SiO_2	.51
CO_2(cal)	43.77
Total	100.14

Analysis of clay No. 7, from Salt River, Arizona.

Chlorine	.20
Silica	50.51
Fe_2O_3	5.03
Al_2O_3 and P_2O_5	14.63
TiO_2	.66
MnO	.03
CaO	6.77
MgO	3.00
K_2O	3.06
Na_2O	2.18
Loss at red heat	13.30
Total	99.37

Altogether these results are very gratifying, and prove beyond question the existence of convenient and abundant materials from which cement can be made. The greatest difficulty is the scarcity of fuel. There is considerable wood in the reservoir site, mainly cottonwood and mesquite, which it will be desirable to clear out of the reservoir in any event. Wood is not suitable for burning cement clinker by modern methods, but if made into charcoal and then ground to powder would answer, or oil may be imported for the purpose from California. A large amount of power is required for grinding the rock and the clinker, and a still larger amount will be necessary in the construction of the dam, for excavating to foundation, quarrying and handling the rock, mixing and handling mortar, etc. If steam power were used for all these purposes the small amount of wood at hand would soon be exhausted, and it would be necessary to haul wood a long distance, or to import coal, either of which would be very expensive. Water power can be developed by diverting water from Salt River above the reservoir site, carrying it in a canal above the proposed lake and dropping it through a penstock just below the dam. By such means an ample supply of power can be obtained, available through the construction period and afterwards also, if desired. The chief expense attached to this development will be the construction of the canal for conveying water from the diversion site to the dam site. But as the power will be valuable for other purposes its cost is not entirely chargeable to the dam, and everything considered, this is by far the cheapest manner of obtaining the large amount of power required. This is treated more in detail under the proper heading, page 45.

The estimated cost of the cement plant, with modern machinery capable of producing 300 barrels per day, as furnished by Mr. E. A. Duryee, is as follows:

Approximate cost of a rotary process 2-kiln Portland cement plant of a daily capacity of 300 barrels.

Crusher	$2,000
Mill for disintegrating clay	500
Rotary clay dryer	1,500
Elevators and conveyors for raw materials	1,000
Storage bins for raw materials	1,000
Mills for grinding raw materials	10,000
Two rotary kiln-linings and stacks	15,000
Mills for grinding cement	10,000
300-horsepower electric motors and step-down transformers	9,000
Conveyors and elevators for cement	1,500
Cost of grading and erecting machinery	10,000
Shafting and pulleys, belts, and setting up same	5,000
Buildings and bins for cement	10,000
Office, laboratory, and equipment of same	1,500
Freight	10,000
Plans, specifications, and superintendence	3,000
Total	91,000

A GAGING STATION ON SALT RIVER, HEAD OF CANYON, BELOW MOUTH OF TONTO CREEK.

B. VIEW UP TONTO CREEK FROM THE GORGE.

With such a mill, and using charcoal for burning cement, the cost of manufacture would be approximately as follows, allowing for power only the proportion necessary for maintaining and operating the electric plant provided:

Cost per barrel of making cement at Salt River dam site, Tonto Basin.

Labor and superintendence	$0.70
Raw materials	.30
Fuel for burning	.90
Power (maintenance and operation only)	.05
Repairs and sundries	.05
Total	2.00

ROADS AND BRIDGES.

The road from Globe to Payson passes through the reservoir almost its entire length. In case of the construction of the dam this road would be submerged, and it will be necessary to provide a new one around the reservoir. If it were deflected to the east it would be thrown into exceedingly rough mountain country, where the construction would be very expensive and the road beset by heavy grades. By passing to the west of the reservoir it would be necessary to use the dam as a viaduct and to build bridges across the spillways. There would not be a great amount of road construction, and this plan would be far cheaper and furnish a much better road than could be built east of the reservoir. The road to the dam site would be necessary in the construction of the dam, and some sort of passageway over the spillways would be necessary in operating the gates.

In view of the contemplated manufacture of cement near the dam and the high cost of steel delivered at the site, it has been decided to build the bridges of the Melan arch type—that is, a light steel skeleton embedded in concrete. This will be about as cheap and far more substantial and permanent than a steel bridge, and more in keeping with the massive and permanent character of the dam. Each bridge is designed to abut at one end on the dam and the other end on the solid rock of the hill, and will have one pier. The spans of each bridge will be 110 feet and 75 feet in the clear. The general design is shown in Pl. XX. They are both similar to bridges that have been in successful use for years and involve no new or untried features.

DAMAGES.

The surveys show about 740 acres of cultivated land that will be submerged by the reservoir. The improvements on these lands consist mainly of small frame or adobe houses, fences, and irrigation ditches. It is thought that an average value of $50 per acre for these lands should be ample to include all improvements. About 4,400 acres of unimproved land is also in private hands, and has little or no value. Allowing $1.25 per acre for such lands, we have a total for damages of $42,500.

The balance of the reservoir site—about 9,000 acres—is publi the control of which is in litigation, and will not be included estimate.

COST.

The following estimates are based upon the data at hand in 1902, and are subject to modification:

Estimated cost of Salt River storage dam.

[247 feet above foundation; 190 feet available storage. Capacity, 840,000 acre-fee

257,420 cubic yards rubble masonry, exclusive of power and cement, at $3.50 a yard	
Cement plant	
Power plant, house, and canal	
Manufacture of 150,000 barrels Portland cement, at $2 a barrel	
Excavation of foundation and river diversion	
Outlet tunnels and lining	
Gates and machinery	
Outlet towers, shafts, and houses	
Viaducts across spillways	
Roads	
Engineering and contingencies, 15 per cent	
Total cost of structures	1,
Damage to private lands	
	1,

Cost per acre-foot, $2.27.

The cost of dam 20 feet lower, storing 600,000 acre-feet, wo practically the same for all items except the masonry and c which would be about 20 per cent less, making the total cost $1,680,000, or $2.75 per acre-foot capacity.

ACKNOWLEDGMENTS.

Generous assistance and valuable suggestions relative to the s of the problems discussed in this report have been received numerous sources.

Especial mention is due to the work of Mr. C. R. Olberg, w principal assistant has performed the major portion of the volum computations and most of the detailed designing connected wi structures adopted for the Salt River reservoir, and has display this work a commendable degree of skill and conscientious care.

Thanks are due to Mr. W. H. Code for the benefit of his val experience in pumping water by electric power for irrigation a his advice regarding the relative quantities of water consumed various months of the year.

Acknowledgments are also due to Mr. F. P. Trott for valuable mation concerning the water supply and for surveys on the McD reservoir site, the latter being made at considerable expense t and freely furnished in the public interest.

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LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., July 10, 1902.

SIR: I have the honor to transmit herewith, for publication as Water-Supply and Irrigation Paper No. 74, a manuscript by Mr. A. L. Fellows on the water resources of the State of Colorado.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF COLORADO.

By A. L. Fellows.

INTRODUCTION.

The State of Colorado, located as it is in the midst of the Rocky Mountains, the crest of the continent crossing it from north to south, and comprising as it does a vast variety of physical conditions, varying from those of the highest mountain regions, where vegetation ceases to flourish, to plains where fruits almost semitropical may be raised, furnishes a diversity of problems connected with the disposition of its water supply unequaled in number and difficulty, perhaps, by those arising in any other State in the Union. The snows of winter, falling upon the continental divide, may furnish the moisture by which the herbage and trees of the mountains are watered, and the waters from these heights, collected in rivulets and streams, may supply the motive power for operating the stamp mills for the mines of the State, or may develop electric power that may be transmitted for running factories, or may be used for sifting out the particles of gold in the placers along the streams of both the Pacific and the Atlantic watersheds. Again the brooks and creeks, collected into larger streams or rivers, enter the broad plains of the eastern half of the State or the canyon and mesa country of the western half, and furnish the lifeblood of vast irrigated tracts, where crops of the most diverse kinds may be raised for the sustenance of countless families, and thus become the assets upon which agricultural communities may draw, whether they are dependent upon wheat raising, sugar factories, potatoes for the Eastern market, alfalfa for feeding lambs and sheep,[a] or any other of the numerous forms of agricultural industry practiced in Colorado. Its water supply therefore becomes of the utmost importance to the State, and it is with the hope that the compilation of all figures readily obtainable bearing upon the subject may prove of interest and value to the people, not only of Colorado, but of States similarly situated, that the preparation of this paper is undertaken.

[a] Colorado Agricultural College Bulletins.

SOURCES OF INFORMATION.

For a period of about sixteen years the measurement of streams has been carried on more or less systematically in the State both by the Hydrographic Division of the United States Geological Survey and by the State engineer's office, working at times in cooperation and at times separately, but always with the same end in view—that of throwing as much light as possible on the discharge of the streams and of determining the feasibility of storing water in available reservoirs whenever the need for such storage should become apparent. The discharge measurements given in this paper are compiled from the records of these offices. When the different records are found to be conflicting, as they sometimes appear to be, credence is given, after careful consultation with those most intimately acquainted with the existing conditions, to the one appearing to be the most likely to be correct.

The records of the United States Geological Survey and of the State engineer's office are the two principal sources from which the following tables are compiled, but information has also been obtained from engineers located in different parts of the State wherever it was possible, and in such cases due credit is given.

The drainage areas given are computed from the General Land Office maps by means of the planimeter, these being the figures accepted in the reports of the United States Geological Survey. The descriptions of streams and drainage basins and of reservoir sites are compiled largely from bulletins, irrigation papers, and reports previously published, but to a considerable extent also from personal examination and knowledge. In the computations use has been made of the tables given in Bulletin of the U. S. Geological Survey No. 140, pages 14 to 32, and Water-Supply and Irrigation Paper No. 27, page 96, to which readers are referred for directions concerning the use of meter and computations of discharge.[a] In a paper of the size to which this must be limited, it is, of course, impossible to give complete results of discharge measurements and of daily gage readings. It has been thought best, therefore, to limit the data given for each station to a table of gagings and to a general table giving the average flow for each month, the average for each year, the maximum and minimum flow for each year, and the most important data connected with the stream measured. With each table is given a brief description of the station at which the results were obtained, showing the value of these results, the prevailing conditions, and the sources from which the information was derived. References are made, wherever

[a] See also, for methods of making measurements, Annual Reports U. S. Geol. Survey: Tenth, Part II, pp. 78 to 86; Eleventh, Part II, pp. 2 to 22; Fourteenth, Part II, pp. 96 to 100; Nineteenth, Part IV, pp. 18 to 31; Twentieth, Part IV, pp. 20 to 22. Also, State Engineers' Biennial Reports: Second, pp. 5 to 9; Third, p. 5; Fourth, pp. 59 to 88; Fifth, pp. 346 to 349; Sixth, p. 8; Seventh, pp. 196 to 217; and Irrigation Bulletin No. 1.

they are deemed desirable, to the reports or water-supply papers of the United States Geological Survey that give more detailed information, so that any reader looking up discharge data upon any particular stream may be assisted in his search for the most complete information.[a] For greater convenience of reference the following table, showing the publications most fully covering the hydrographic work for each year from 1883 to 1900 inclusive, is given below:

Reports of the State engineers of Colorado.

Second Biennial Report, 1883–1884.
Third Biennial Report, 1885-1886.
Fourth Biennial Report, Parts I and II, 1887–1888.
Fifth Biennial Report, Parts I and II, 1889–1890.
Sixth Biennial Report, 1891–1892.
Seventh Biennial Report, Parts I and II, 1893–1894.
Eighth Biennial Report, 1895–1896.
Ninth Biennial Report, 1897–1898.
Tenth Biennial Report, 1899–1900.

Publications of the United States Geological Survey.

Tenth Annual Report, Part II, 1888.
Eleventh Annual Report, Part II, 1889.
Twelfth Annual Report, Part II, 1890.
Thirteenth Annual Report, Part III, 1891.
Fourteenth Annual Report, Part II, 1892.
Bulletin No. 131, Report of Progress of the Division of Hydrography, 1893.
Bulletin No. 131, Report of Progress of the Division of Hydrography; also Sixteenth Annual Report, Part II, 1894.
Bulletin No. 140, Report of Progress of the Division of Hydrography for the Calendar Year 1895; also Seventeenth Annual Report, Part II, 1895.
Eighteenth Annual Report, Part IV; also Water-Supply and Irrigation Paper No. 11, 1896.
Nineteenth Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 15 and 16, 1897.
Twentieth Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 27 and 28, 1898.
Twenty-first Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 35, 36, 37, 38, and 39, 1899.
Twenty-second Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 47, 48, 49, 50, 51, and 52, 1900.

In the compilation of this paper assistance has been given by many different persons and corporations interested in the use of water, and to all these thanks are extended. The attempt has been made to give proper credit in all cases where such assistance has been furnished. The illustrations are selected from photographs made under the auspices of the Survey, and from those furnished by parties assisting in the preparation of this paper.

[a] It is not intended that the references to publications relating to this subject shall form a complete bibliography, but an attempt is made to assist the reader in finding some of the most easily obtainable information on the subjects considered.

VALUE OF SUPPLY.

The mining industries of Colorado depend very largely upon the water supply of the mountain region for the development of power by which stamp mills and sampling works may be operated, and the mining towns are dependent upon electric-light and power plants operated by water; and the mills and factories of the State are, to a greater and greater extent, being run by the same means; further, the cultivation of between two and three millions of acres of land is made possible by water used in irrigation; and when it is seen that this water supply is so limited that the normal flow of very many of the streams is entirely exhausted and that already recourse is being had to storage in reservoirs, built to conserve, for use in seasons of low water, floodwater that would otherwise go to waste, it will then be evident that its water supply is of the greatest moment to the State. This fact has been recognized by the people themselves ever since the State was formed, and a complicated system of laws has been built up controlling the water and its distribution among consumers. This subject has already been fully treated in a number of different bulletins and papers, among which are Water-Supply and Irrigation Paper No. 9, U. S. Geological Survey, and Bulletins Nos. 58 and 60 of the United States Department of Agriculture, as well as the Irrigation Laws of Colorado, as compiled and furnished by the State engineer's office, so that nothing more than a brief discussion as to the ownership of water by Colorado is necessary at this time.

By the State constitution the water is declared the property of the State, and as such is to be distributed and used in accordance with its occurrence and availability. The entire system of State laws distributing the water among consumers is based upon this plan, the State engineer being made, next to the courts, the head of the department having immediate supervision of the subject, and being the final authority on questions relating to the use of water, subject to appeal to the courts. Next to him and his deputies are the superintendents of the various irrigation divisions, of which there are 6, each of them comprising lands drained by one of the six principal streams of the State; namely, the South Platte, the Arkansas, the Rio Grande, the San Juan, the Grand, and the Green rivers. Each of these divisions in turn is divided into water districts, each one comprising one or more of the tributaries of the various large streams, or parts of the main streams themselves, each district, of which there are 69 in the State, being under the supervision of a water commissioner, whose duty it is to regulate the use of the water under his immediate jurisdiction, appeals being possible from the commissioner to the superintendent, from the superintendent to the State engineer, and from the State engineer to the courts. This partition of the State into divi-

sions and districts will be treated more fully later, so that further description is unnecessary at present.

The uses of the water are so numerous and varied that the administration of the laws relating to water is very difficult. In Colorado the riparian doctrine does not obtain, so that this complication is removed—at least unless decisions should be rendered in the United States courts acknowledging such rights as belonging to the States into which the streams flowing out of Colorado run—but the complications are numerous enough as it is. The supply of water is so limited compared with the demands for it that early rights or priorities become of the utmost importance. The principal uses to which the water may be put may be classified in the order of importance as domestic use, irrigation, mining, and milling. The use of the normal flow of the streams is considered as of first importance, the use of stored water being a matter for secondary consideration.

The order in which water would naturally be used, however, is different, and, leaving out of consideration entirely for the present the fact that priority of use may determine right to use, it is obvious that the physical nature of the State has an important bearing upon the problems of use. The mines being situated in the mountains, and the natural conditions being usually such that the clearest and best water is found at the higher altitudes, it is evident that, other things being equal, water for domestic use and for mining would be demanded at the highest available points upon each stream. After the water begins to find its way into canyons and over waterfalls—in other words, when it is discharging from the mountains into the plains—the conditions evidently become more favorable for the development of power, the fall of the streams being rapid, and the quantities being sufficient for such use. Again, after the water debouches from the mountainous area and enters the plains, it is evident that irrigation may be practiced upon a broader scale, so that the order of use upon a stream would naturally be domestic use, mining, milling, and water power, and, finally, irrigation.

The brief discussion of the uses to which the water may be put in Colorado sufficiently demonstrates the importance of the subject. It is not within the province of this paper to treat of the administration of the laws, or to discuss the subject of priorities. Its intention is simply to show, so far as possible, how much water is available for use in some of the streams of the State, and to indicate briefly, by examples, something of what is being done in harnessing this, one of the greatest dynamics of nature, for the use of man. At the same time an effort will be made to show the necessity for the storage of the waters that now go to waste in the winter seasons and at flood stages, in order that there may be the most economical and thorough use of this great resource. That the period when storage is demanded

is already at hand is clear to all students of the hydrography of the State, for the normal flow of the majority of the streams is already utilized and exhausted. It is not now proposed to discuss the most economical use of water—that water is used in Colorado most extravagantly and in ways that would not be tolerated in a country more advanced in scientific irrigation is beyond question—but simply to consider the present use of water and endeavor to devise methods by which this use may be extended, so far as possible, under existing conditions. Necessity will compel more economical use in the future; but the present most urgent need is that the water which now goes to waste and is of no service to man shall be conserved so as to be available for beneficial use. Such streams as the South Platte, the Cache la Poudre, the Arkansas and its tributaries, the Rio Grande, and numerous other streams, furnish normally an insufficient supply for present needs, but if the flow could be equalized by the storage of water in reservoirs the irrigated area in Colorado might be greatly extended. The importance of this fact is already felt, and in many places, as upon the Big Thompson, the Cache la Poudre, and the Arkansas, considerable water is already being stored, to the great benefit of the people within the irrigable territory lying below the reservoirs.

RUN-OFF.

The physical conditions affecting the run-off in the State of Colorado are so various that it is impossible to formulate an even approximately correct rule as to the percentage of the rainfall carried from the drainage area into the streams.[a] In case of a violent storm of the nature of a cloud-burst in a rocky, mountainous district, as much as 75 or 80 per cent of the precipitation may be collected into the nearest streams; it will, however, be largely taken up by percolation into the soil before it has run a very great distance. On the other hand, a great amount of water falling gently upon a sandy plain may be entirely absorbed by the soil and may evaporate before any water whatsoever has run off. Computations of the percentage of run-off are often misleading, also, from the fact that water is being constantly taken out of the various streams for irrigation. For example, no accurate estimate could be made from the discharge of the Arkansas River at Rockyford as to the percentage of run-off from the drainage area above, as water is constantly being taken out for reservoirs and for direct irrigation, and the amount so taken can hardly be calculated unless a complete record is made of the intake of each canal, whether large or small, along the Arkansas and all its tributaries. Where there are no irrigating canals or ditches along a stream it is comparatively easy to determine the percentage of the total precipitation contained in the

[a] See also Biennial Reports of the State Engineer: Second, pp. 10-18; Fourth, pp. 17-23.

run-off at a given point; but when water is diverted from a stream in such quantities that only a comparatively small portion returns, the determination of run-off becomes difficult. Where gaging stations are located at the mouths of canyons, however, above which there is little, if any, diversion, the percentage may be determined with reasonable accuracy, although even then it is difficult to find points on any of the streams above all diversion for irrigation and yet far enough down to be of great use in the determination of run-off. For example, on the St. Vrain, the discharge at the gaging station at Lyons will not give correctly the run-off of the drainage basin above, for the reason that meadows are being irrigated at places far above the gaging station. The Boulder, again, is at times losing water that is being stored in reservoirs high up in the basin, and such is the case with the majority of the other streams. For these reasons no attempt has been made to determine what relation the total precipitation bears to the run-off. Readers interested in these computations are referred to Part IV of the Twentieth Annual Report of the United States Geological Survey. That the run-off does depend upon the precipitation, however, is self-evident, and for this reason a table giving the precipitation at various points in the State, beginning with the year 1896, is furnished. A comparison of the depth of the run-off in inches, as given in the tables of discharge, with the precipitation in inches for a given year, will give an approximately correct idea of the amount of water flowing in a stream at any given point.[a]

Normal temperature and precipitation at stations in Colorado.

[Compiled from the records of the Office of the U. S. Weather Bureau, at Denver, Colo. F. H. Brandenburg, section director.]

Station.	County.	Elevation.	Length of record.	Normal temperature.	Precipitation (in inches).					Normal to 1899, inclusive.
					1896.	1897.	1898.	1899.	1900.	
South Platte drainage:		*Feet.*	*Years.*	°*F.*						
Boxelder	Larimer	6,950	10	.....	17.83	21.42	16.34	14.42	17.93	16.46
Laporte	do	5,069	10	.....	15.49	17.72	13.63	13.34	20.06	14.37
Fort Collins	do	4,995	20	46.8	15.76	15.24	11.03	16.19	19.21	13.86
Greeley	Weld	4,637	11	47.5	13.52	16.09	(b)	10.79	11.51	11.83
Moraine	Larimer	7,900	11	40.6	17.28	18.87	16.86	16.58	16.72	17.56
Dumont	Clear Creek	8,000	10	.....	15.01	20.82	17.16	18.19	19.54	18.59
Denver	Arapahoe	5,291	29	49.8	11.84	15.37	12.98	9.33	15.29	14.15
Castlerock	Douglas	6,220	10	46.3	20.44	(b)	(b)	14.70	14.70	18.59
Hamps	Elbert	5,500	8	45.8	12 78	(b)	12.57	12.67	21.17	12.26

[a] See Reports of the Weather Bureau; also U. S. Geological Survey Reports: Tenth, Part II, pp. 13–14; Eleventh, Part II, pp. 23, 25, 205, 214, 251, and 281; Twelfth, Part II, pp. 226, 230, 231, and 245; Thirteenth, Part III, pp. 25, 28, and 153; Fourteenth, Part II, pp. 150–152; and Biennial Reports of the State Engineers of Colorado: Second, pp. 14–17; and Fifth, Part I, p. 534. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 91.

[b] Record incomplete.

Normal temperature and precipitation at stations in Colorado—Continued.

Station.	County.	Elevation.	Length of record.	Normal temperature.	Precipitation (in inches). 1896.	1897.	1898.	1899.	1900.	Normal to 1899, inclusive.
		Feet.	*Years.*	° *F.*						
Kansas drainage:										
Leroy	Logan	4,380	12	48.1	14.18	18.48	14.95	13.22	14.74	15.10
Yuma	Yuma	4,128	10	.....	15.84	18.30	20.39	14.61	17.98	16.63
Wray	do	3,512	7	.....	16.68	20.19	18.71	10.74	18.24	15.13
Cope	Arapahoe	.....	9	50.1	(a)	(a)	28.48	(a)	21.47	18.42
Fox	do	.....	9	.....	(a)	17.19	20.84	10.06	19.92	15.56
Seibert	Kit Carson	4,705	9	.....	14.42	20.94	18.65	12.62	20.79	14.31
Cheyenne Wells.	Cheyenne	4,259	8	.....	(a)	(a)	18.50	14.01	18.60	15.76
Arkansas drainage:										
Lake Moraine.	El Paso	10,268	7	.....	19.70	30.32	23.14	18.59	33.46	22.55
Gleneyre	do	6,500	9	46.7	15.53	(a)	(a)	(a)	19.34	13.98
Colorado Springs.	do	6,098	21	.....	13.94	(a)	(a)	8.81	13.64	14.13
Leadville	Lake	10,185	8	.....	(a)	15.51	12.27	19.86	13.50	14.21
Twin Lakes	do	9,200	7	.....	(a)	(a)	(a)	(a)	13.76	15.35
Canyon	Fremont	5,363	12	.....	11.96	11.13	11.45	9.80	14.34	11.70
Pueblo	Pueblo	4,734	12	.....	10.81	12.71	10.85	13.05	13.37	11.53
Rockyford	Otero	4,177	12	.....	9.74	(a)	16.04	18.68	15.60	13.52
Las Animas	Bent	3,892	33	.....	11.81	10.89	15.63	12.11	15.48	11.19
Lamar	Prowers	3,592	11	.....	(a)	15.10	17.84	19.64	19.64	15.17
Westcliffe	Custer	7,864	8	.....	13.27	(a)	16.88	12.81	16.31	17.29
Clear View	Las Animas	9,500	11	.....	24.00	31.76	27.31	18.49	23.08	24.23
Hoehne	do	5,721	9	.....	16.05	11.80	14.07	12.36	13.30	13.92
Springfield	Baca	4,400	9	.....	(a)	(a)	20.75	12.78	22.68	18.36
Vilas	do	4,158	10	.....	(a)	(a)	(a)	15.48	19.66	13.74
Rio Grande drainage:										
Saguache	Saguache	7,740	10	42.0	(a)	8.84	8.06	5.96	6.25	7.52
San Luis	Costilla	7,596	10	42.3	12.31	13.93	14.20	10.04	10.16	13.06
San Juan drainage:										
Durango	La Plata	6,534	8	47.3	(a)	24.93	16.27	14.49	9.86	17.98
Mancos	Montezuma	7,008	2	45.6	(a)	(a)	(a)	12.35	12.44	(a)
Grand drainage:										
Breckenridge	Summit	9,524	12	33.2	24.03	24.49	16.29	29.41	14.62	29.44
Parachute	Garfield	5,105	9	49.8	(a)	(a)	(a)	18.14	7.89	11.37
G. S. ranch	Mesa	5,200	14	52.1	(a)	14.45	8.37	13.17	6.09	11.77
Grand Junction	do	4,608	10	49.2	8.22	11.10	5.45	10.87	3.64	8.89
Cedar Edge	Delta	6,175	9	.....	9.33	15.05	9.48	10.90	9.67	11.89
Delta	do	4,980	12	.....	(a)	11.87	4.72	8.44	5.19	8.78
Antlers	Garfield	5,350	15	.....	(a)	17.92	9.16	15.81	5.82	(a)
Green drainage:										
Meeker	Rio Blanco	6,182	8	.....	16.28	24.30	13.34	20.05	(a)	b16.92
Pagoda	Routt	6,500	9	41.1	17.38	29.13	18.92	24.05	12.32	20.53
Lay	do	6,200	7	.....	14.04	(a)	(a)	(a)	7.60	13.62

a Record incomplete. b Normal to 1898, inclusive.

As has been suggested, the run-off of a mountainous area will differ very considerably from the run-off of an equal area on the plains. A

given amount of precipitation in South Park, for example, will furnish to the same stream a very much greater run-off than the same amount of precipitation on the plains north of Sterling, the more rocky and broken by ravines the territory the greater being the percentage of run-off. The character of the rock formation and the nature of the canyons through which the water flows also have important bearings upon this percentage. Twelve inches of precipitation on the headwaters of the Arkansas will furnish a greater percentage of run-off than the same amount falling on an equal area of the Mesa Verde, in southwestern Colorado, the rock in the former case absorbing little water and the soil being of such nature that the water does not percolate through it to a very great extent, and the rock in the latter case being a soft sandstone and the ravines having sandy beds. For these reasons it is evident that to determine the run-off at any particular point a series of stream measurements must be made, for determinations based solely on the precipitation of a region would be only approximate.

The effect of forests in conserving moisture and in rendering the discharge of the streams more equal throughout the year is thoroughly demonstrated and generally admitted.[a] Whether or not the presence of forests increases precipitation in a given territory is of little importance compared with the question of the extent to which the forest keeps back the floods of the spring and early summer for later use. An examination of discharge tables obtained at stations that have been long maintained will show that the high-water stage is becoming each year earlier and of shorter duration. It is self-evident that anything that will tend to equalize the flow of streams throughout the year has an important bearing on the use of water. A given stream may be adequate to irrigate all the cultivable land along its borders if its water can be properly distributed throughout the irrigating season. When, however, as is the case upon many streams, the water runs off rapidly in May and in the early part of June, it will happen that while there is a great surplus of running water during the early part of the year, yet the stream may be nearly dry at a time when a great deal of water is needed for irrigation. This is the case, for example, upon the Mancos River, in the southwestern part of the State, in which during the month of May enough water goes to waste to furnish all the adjacent irrigable land with a sufficient supply if it could be properly stored.

In studying this question one should not fall into the error of supposing that in order to make the most economical and satisfactory use of the water the supply should be equal throughout the summer

[a] See Fifth Biennial Report of the State Engineer of Colorado, p. 43; Bulletin No. 55, Colorado Agricultural Experiment Station; Twentieth Annual Report, U. S. Geological Survey, Part V, and reports of the Forestry Division of the Department of Agriculture.

season. Usually more water is needed in the latter part of May and in early June than would be required in any other month; that is to say, the duty of water—the area of land that may be served by a given quantity of water—is least in May and June, and increases rapidly toward the end of the season, so that it would be a mistake to suppose that if, for example, 100 cubic feet per second were required for a given area at the time when most water was needed, that provision must also be made for a flow of 100 cubic feet per second regularly throughout the remainder of the so-called irrigation season. Such a run of water at a time when little of it was being used could not do otherwise than cause great damage by washing away the soil and making swamps of the lowlands. The amount of water used at various seasons will depend largely on the kind of crops raised and on the nature of the season. This phase of the irrigation problem is being studied by the Agricultural Department, and a number of bulletins and papers have already been written on this subject,[a] as well as on loss of water by seepage and evaporation.[b] It is therefore sufficient here to call attention to the facts that when the run-off is the greatest the use of water is also generally the greatest, and that the amount of water required diminishes somewhat as the normal supply itself diminishes, only less rapidly; so that the most economical use of the water of a given stream is obtained when all the land along that stream is cultivated that can be supplied with water directly from the stream itself for about two months of the year, the balance of the supply being stored from waters that would otherwise have gone to waste during the high stages, and the amount of land cultivated being so regulated that practically all of the water is used.

On streams where there is no flow normally, as is usually the case with the streams of the plains, the supply consisting almost entirely of a discharge lasting a few hours only during and after storms, the situation is, of course, different. If all of the water of such streams can be stored in reservoirs, it may be drawn off gradually and used for irrigation. The chief difficulties in such cases are that the water usually comes down in great quantities very heavily laden with silt, so that it is almost impracticable to construct canals that will carry it without either erosion or filling, and that reservoirs constructed in the beds of such streams usually fill with sediment very quickly. Sometimes, however, a stream is so fortunate in its situation and regimen

[a] Bulletins of the U. S. Department of Agriculture, Office of Experiment Stations, Nos. 73, 81, and 86, and Bulletin No. 22 of the Agricultural Experiment Station at Fort Collins, Colo., and U. S. Geological Survey Annual Reports as follows (see indices of same, under Duty of Water): Tenth, Part II; Eleventh, Part II; Twelfth, Part II; Thirteenth, Part III; and Fifth State Engineer's Report, p. 46; Sixth, p. 67; Seventh, p. 7; Eighth, p. 20; Ninth, pp. 17, 51, and 59. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 95.

[b] Bulletins Nos. 45 and 48, Agricultural Experiment Station, Fort Collins, Colo., and U. S. Geological Survey Annual Reports as follows (see indices of same, under Evaporation): Eleventh, Part II; Twelfth, Part II; Thirteenth, Part III; Fourteenth, Part II; Twentieth, Part II; also Bulletin No. 140.

that a considerable portion of its water may be drawn away from the channel in which it flows and diverted to some adjacent reservoir site. The chief differences, therefore, between a mountain or perennial stream and one flowing on the plains are that irrigation may be practiced from the first by water taken directly from the stream, while the water from the second must be stored before it can be used, and that the water of one is comparatively clear, while that of the other is inordinately filled with silt.

The storage of surplus water is a great problem in itself. In many localities where there is plenty of water that is going to waste no satisfactory reservoir sites are available; on the other hand, many of the best reservoir sites of the State are in localities where it is difficult to get water to them from the natural streams. Few people, comparatively speaking, realize how large a reservoir must be to supply any considerable amount of land with water for irrigation. Those who have reservoir propositions in view should bear in mind that where land is to be irrigated entirely by means of the water stored in a reservoir it will, making all necessary allowances, take approximately 2 acre-feet—that is, 2 acres covered with water 1 foot deep, or, what amounts to the same thing, 1 acre covered with water 2 feet deep—to irrigate a single acre of land for a season; so that to irrigate 1,000 acres of land would require a reservoir, let us say, covering an area of 100 acres 20 feet deep, if all the water is to be derived from this source and none directly from the stream. This suggestion is made for the reason that persons often recommend the examination of a reservoir site which they say would store water for a whole township, whereas in reality it would furnish little more than enough for stock use for a good-sized cattle ranch. That there are many available reservoir sites, however, throughout the State, is beyond question, and information and data concerning such sites is always gladly received. A few of the more important sites already examined will be mentioned from time to time in this paper.

WINTER DISCHARGE.

In compiling the tables given hereafter the records for the winter months have usually been accepted as furnished by the observers. It is, however, unsafe to trust these records unreservedly, for in nearly all of our mountain streams ice gorges are constantly being formed in winter, changing the velocity of the current and the gage height recorded by the observer without materially changing the discharge of the stream. It is often safer to strike an average between the November flow and the flow of about the middle of March or the first of April following than to trust to the apparent discharge as derived from the observations. For this reason the winter discharge has been

omitted from a number of stations where the figures if given would have been absolutely misleading; they are retained, however, in a few stations, and where any false impression might arise from the figures given, attention is called to that fact in a footnote.

EXPLANATION OF TABLES.

In general the tables given in this paper are summarized from all available data. For stations where records exist for from one to three years only the discharge is given for each year individually, but for stations where records have been maintained for four or more years the average discharge is usually given for each month during which the record was kept and these averages are again averaged, giving a normal discharge for each month as computed for that month of each year during which records were kept, these being again averaged for a normal year or that portion of the year covered by the records. The discharge in second feet per square mile given in the vertical columns in these tables is the amount corresponding to the average flow for the same months or periods, the depth in inches being derived directly from the flow in second feet per square mile and corresponding thereto. The discharge for that portion of each year covered by the record, or for the whole year, as the case may be, is averaged and placed below the record for that year. The number of acre-feet given is in each case the corresponding amount for the period covered. The number of second-feet per square mile is derived from the average flow for the period covered, and the depth of run-off in inches is derived from them, usually for a thirty-day period, but at times for the entire year or for the entire period covered, the variations being mentioned in the accompanying footnote in each case. It is believed that the footnote accompanying each table is sufficient for further explanation of the table.

IRRIGATION SYSTEM.

As has already been mentioned, the State of Colorado is divided into six irrigation divisions, each comprising a considerable portion of the State, drained usually by a single stream and its tributaries, these divisions being in their turn divided into districts (see Pl. I), as will be more fully described later.[a]

The six divisions are as follows: Division No. I, or South Platte River; No. II, or Arkansas River; No. III, or Rio Grande; No. IV, or San Juan River; No. V, or Grand River; No. VI, or Green River; each consisting in general of the territory drained by the stream (with its tributaries) from which the division takes its name.

[a] Bulletins Nos. 58, 60, and 73, Office of Experiment Stations, U. S. Department of Agriculture; Water-Supply and Irrigation Paper No. 9, U. S. Geological Survey, and reports of the State Engineers of Colorado.

SOUTH PLATTE DIVISION.

DRAINAGE.

Division No. I, or South Platte River division,[a] consists of the territory drained by South Platte River and its tributaries, but includes also North Park, drained by the North Platte and its tributaries, in which are located water districts Nos. 46, 47, and 48. Water district No. 65 is also included, which covers the territory within the northern half of the Kansas River Basin in Colorado drained by Frenchman Creek, the North Fork of the Republican, and the Arikaree. The two latter streams, however, in district No. 65, are of little importance, so far as irrigation in Colorado is concerned, as they head too near the eastern border of the State and carry too small amounts of water to be of much value.[b] The country drained by these streams varies in altitude from about 5,000 down to 3,800 feet above sea level. This area is what has been known in the past as the rain-belt country, and for some years there was a general belief that farming could be practiced successfully in that region without irrigation, but such farming has not been found to be profitable, and agriculture in that section hereafter will be generally limited to small tracts that can be irrigated, either directly from the streams or by means of storage. In some cases artesian wells produce a flow sufficient for stock use and for the cultivation of small patches of ground. No gaging stations have been established upon any of these streams.

The streams of North Park are of more importance. District No. 46 consists of the territory drained by the North Platte proper in Colorado as far down as its junction with Middle Fork. No. 47 consists of the territory drained by the Middle Fork and its tributaries and the North Platte below its junction with Middle Fork. No. 48 consists of the drainage basin of the Laramie and its tributaries. The territory comprising North Park is in general a rolling, more or less timbered country, with numerous small streams flowing through it. The principal industry is stock raising, crop raising being limited to hay and grain. Little irrigation is practiced, this being limited principally to hay meadows. On the Laramie, however, a complication arises from the fact that a canal, called Skyline canal, takes a considerable portion of the upper tributaries across the divide into the drainage of the South Platte River, taking water away from the State of Wyoming and using it in the drainage basin of the South Platte.[c] No measurements are made in Colorado upon the tributaries

[a] State Engineers' Reports: Second, p. 26; fourth, pp. 35 and 46; fifth, p. 63, and sixth, p. 67. For details concerning the different districts, see the Biennial Reports of State Engineers; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 94 et seq.

[b] See list of miscellaneous measurements, page 69.

[c] See Hayden's Reports; also Nineteenth Annual Report U. S. Geological Survey, Part IV, p. 300; Twentieth Annual Report, Part IV, p. 393; Water-Supply and Irrigation Paper No. 9, p. 42. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97, etc.

of the North Platte, but a station has been maintained for some years upon the Laramie at Woods, in Wyoming, a few miles north of the State line, and the results of these measurements are given in the table for the Laramie at that point (page 60).

The South Platte River itself rises in South Park and flows in a generally northeasterly direction to the northeast corner of the State, which it leaves at a point a short distance below Julesburg. The drainage basin has been so fully described in previous reports and irrigation papers that only a brief description is necessary, the reader being referred to those already printed.[a] In general, the western side of the division is very mountainous, the main stream itself and all the tributaries of that section issuing from high mountains through deep canyons, many of them, however, draining parks at the headwaters, where stock raising and some cultivation of hay is carried on. From the eastern slope of the foothills to the eastern boundary of the State the country is of the plains character, and the streams draining this section are torrential in their nature. The normal flow throughout this entire division is claimed and used for irrigation, but in the high stages of the streams and in the winter season a great deal of water goes to waste which might be stored in suitable reservoirs.

The water districts now included in this division are Nos. 23,[b] 8,[c] 2,[d] 1,[e] and 64,[e] on the South Platte River; No. 9,[f] comprising the territory drained by Bear Creek; No. 7,[g] by Clear Creek; No. 6,[h] by Boulder Creek; No. 5,[h] by St. Vrain Creek; No. 4,[i] by Big Thompson Creek; No. 3,[i] by Cache la Poudre River; Nos. 46, 47, and 48,[j] by tributaries of North Platte River; and No. 65 by tributaries of Kansas River, the latter district being more properly outside of the South Platte River division, although legally a part of it.

STREAM MEASUREMENTS.

The following stations have been maintained for a greater or less time in or near the South Platte division: Cheesman Lake, Platte Canyon, Denver, and Orchard on South Platte River; Morrison, on Bear

[a] See U. S. Geological and Geographical Survey Terr., Hayden, 1875 and 1876. Annual Reports U. S. Geological Survey: Tenth, Part II, p. 69; Thirteenth, Part III, p. 82; Sixteenth, Part II, p. 542; Eighteenth, Part IV, p. 159; Nineteenth, Part IV, p. 311; Twentieth, Part IV, p. 277; Twenty-first, Part IV, p. 200. Also Bulletins No. 131, p. 30, and No. 140, p. 102; Water-Supply and Irrigation Paper No. 37, p. 221; No. 49, p. 278, and Tenth Biennial Report State Engineer of Colorado, p. 246.

[b] Fifth Biennial Report, Part II, Pl. I.

[c] Ibid., Pl. VII; also Seventh Biennial Report.

[d] Ibid., Pl. III; also Seventh.

[e] Ibid., Pl. II; also Seventh.

[f] Ibid., Pl. VIII; also Seventh.

[g] Ibid., Pl. VI; also Seventh.

[h] Ibid., Pl. V; also Seventh.

[i] Ibid., Pl. IV.

[j] Nos. 46, 47, 48, and 65 have not been mapped.

Creek; Forkscreek, on Clear Creek; Marshall, on South Boulder Creek; Boulder, on Boulder Creek; Lyons, on St. Vrain Creek; Arkins, on Big Thompson Creek; Fort Collins, on Cache la Poudre; and Woods in Wyoming, on Laramie River.

The waters of this division are used in all the different ways previously mentioned. In South Park and in the foothills along the east front of the Rocky Mountains water is being extensively stored for domestic use. In the mountains and in places where the fall is great the water is used for the development of power and also for placer mining. After leaving the mountains it is used for irrigation, and already it is being stored extensively for use late in the irrigation season, this being especially true of the territory along the Big Thompson and Cache la Poudre. Cheesman Lake and some of the other reservoirs of the upper portion of the Platte have already been described,[a] as have also a number of those of northern Colorado.[b] There are undoubtedly enough reservoir sites along the South Platte and its tributaries to store all the water that now goes to waste. A number of these on the plains through which the river flows between Greeley and Julesburg are now under consideration.

SOUTH PLATTE RIVER AT CHEESMAN LAKE.

This station has been maintained by the Denver Union Water Company for the purpose of determining the discharge of the South Platte at that point with reference to the construction of a large reservoir for the purpose of providing a sufficient domestic water supply for the city of Denver and of developing power to be transmitted from the lake to various points below. The dam is to be of solid masonry, 217 feet in height, and is already well under way (see Pl. II). The lake when full will be about 7 miles in length, and the capacity will be probably not less than 4,000,000,000 cubic feet. The same company has other large reservoirs at points lower down, but none of equal magnitude with this.[c]

The records are given for only two years. Those for 1899 are approximate, but those for 1900 have been carefully compiled and are very reliable. They are furnished through the courtesy of Mr. C. L. Harrison, chief engineer of the Denver Union Water Company.[d]

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[a] House Doc. No. 141, Fifty-fifth Congress, second session, H. M. Chittenden's Report; Water-Supply and Irrigation Paper No. 37, p. 221; Twenty-First Annual Report U. S. Geol. Survey, Part IV, fig. 192; Tenth Biennial Report of State Engineer, p. 247.

[b] Water-Supply and Irrigation Paper No. 9, and Chittenden's Report above mentioned.

[c] See Chittenden's Report above mentioned, this reservoir being there called the "South Platte site."

[d] For more detailed information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 248; Water-Supply and Irrigation Paper No. 37, pp. 222-223; No. 39, p. 447, and No. 49, p. 280.

Estimated monthly discharge of South Platte River at Cheesman Lake.

[Drainage area, 1,677 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1899.						
August	902	170	354	21,767	0.21	0.24
September [a]	198	105	149	8,926	.09	.10
October [a]	155	34	92	5,657	.05	.06
November [a]	171	55	125	7,438	.07	.08
December	112	44	70	4,304	.04	.04
Last 5 months of the year			[a] 158	48,092	.09	.52
1900.						
January	27	23	26	1,599	.02	.02
February [b]	27	27	27	1,553	.02	.02
March	103	27	80	4,919	.05	.06
April	547	92	254	15,114	.15	.17
May	1,540	562	1,038	63,824	.62	.71
June	1,945	550	1,204	71,643	.72	.80
July	522	40	208	12,789	.12	.14
August	126	58	88	5,410	.05	.06
September	103	63	79	4,701	.05	.06
October	155	39	84	5,165	.05	.06
November	90	37	69	4,106	.04	.04
December	67	18	33	1,964	.02	.02
The year			[a] 266	192,787	.15	2.16

[a] Average. [b] Estimated in part.

List of discharge measurements made on South Platte River at Cheesman Lake.

[Hydrographer, J. A. Runner.]

Date.	Gage height.	Discharge.	Remarks.
1899.	*Feet.*	*Sec.-ft.*	
July 31	3.62	806	All gagings are made by floats.
September 8	1.45	184	
October 3	1.23	95	
November 19	1.30	107	
December 5	1.24	97	

List of discharge measurements made on Goose Creek at Cheesman Lake.

[Hydrographer, J. A. Runner.]

Date.	Gage height.	Discharge.	Remarks.
1899.	*Feet.*	*Sec.-ft.*	
September 8	0.95	24	All gagings made by floats.
October 8	.84	10	
November 19	.72	8	
December 3	.76	9	

A. DAM AT CHEESMAN LAKE, DOWNSTREAM FACE.

B. DAM AT CHEESMAN LAKE, UPSTREAM FACE.

SOUTH PLATTE RIVER AT PLATTE CANYON.

Records have been kept for a number of years of the discharge of South Platte River at a point a short distance above where it debouches from the mountainous area into the plains. The station was located first at Deansbury, but was later removed to a point about 3 miles downstream, near the pumping station of the Denver Union Water Company. The records for both stations are given in one table, as they are practically the same, no water being used along this section except what is taken out by the Denver Union Water Company at its head gate, which amount would be approximately compensated by the inflow during the same distance. The station is of importance, as it gives the discharge of the river just above the point where it begins to be used on a large scale for irrigation, and is, therefore, of great value in determining the amount available for storage and the percentage of run-off from the territory above. The situation is complicated, however, as has been previously suggested, by the fact that some irrigation is practiced in South Park, for which reason an estimate of the percentage of run-off based upon this record would necessarily be too small. The irrigation ditches of South Park, although small in size, are many in number, and the aggregate of water thus used is considerable. At a point about a mile below the gaging station the first large canal, the Northern Colorado Irrigation Company's canal,[a] is taken out by means of a diverting dam constructed across the river and a tunnel cut through a spur of the canyon wall. The physical conditions at the station are not favorable to extremely accurate measurements, for the channel is filled with bowlders and the current is very rapid. The stream bed is not, however, subject to great change, and for this reason the station has been maintained. Gagings must necessarily be made from a bridge or cable, owning to the depth and velocity of the water. The banks are so high that there is little danger of overflow.[b]

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[a] See Twenty-first Annual Report U. S. Geological Survey, Part IV, p. 200; also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101 and 109.

[b] Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 63, and Part II. Pl. XVII; Fifth, Part I, pp. 19 and 24, and Part II, Pl. XI; Sixth, pp. 19 and 26; Eighth, pp. 412 to 419; Ninth, pp 328 and 329; Tenth, pp. 252 to 255. Annual Reports U. S. Geological Survey: Eighteenth, Part IV, p 159; Nineteenth, Part IV, p. 311; Twentieth, Part IV, p. 280; Twenty-first, Part IV, p. 201. Also, Bulletin U. S. Geological Survey No. 140, p. 103, and Water-Supply and Irrigation Papers, No. 11, p. 52; No 15, p. 87; No. 37, p. 224, No. 39, p. 448, and No. 49, p. 280. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101, 109, 114, and 125.

Discharge of South Platte River at Deansbury and Platte Canyon.

[Drainage area at Deansbury, 2,600 square miles.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1899.	1900.	Mean.	Mean run-off. Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	.....	.....	.....	.....	.....	.....	97	81	.....	98	92	5,657	0.04	0.04
February	.....	.....	.....	.....	.....	.....	.....	115	80	.....	53	83	4,610	.03	.03
March	.....	.....	.....	.....	.....	.....	.....	207	101	.....	156	155	9,531	.06	.07
April	295	.....	[a] 172	.....	[b] 142	.....	.....	473	370	454	826	405	24,100	.16	.18
May	470	.....	478	391	[c] 1,117	[d] 630	.....	502	984	760	[g] 424	862	53,002	.33	.38
June	535	.....	460	403	1,243	628	.....	281	1,046	1,346	(*f*)	743	44,212	.29	.32
July	310	545	324	520	645	847	.....	233	.....	1,161	.....	573	35,233	.22	.25
August	265	550	211	562	373	535	.....	189	.....	587	.....	409	25,148	.16	.18
September	165	410	129	196	219	328	.....	250	.....	233	.....	266	15,828	.10	.11
October	185	300	180	172	.....	292	.....	217	.....	154	.....	214	13,158	.08	.09
November	.....	.....	.....	.....	.....	.....	[e] 241	169	.....	160	.....	190	11,306	.07	.08
December	.....	.....	.....	.....	.....	.....	145	93	.....	160	.....	133	8,177	.05	.06
Mean	318	451	279	374	623	543	193	236	444	557	711	344	249,962	.13	1.79
Acre-feet for period recorded [g]	135,034	109,962	106,922	136,528	187,872	168,012	16,563	170,919	160,395	304,003	212,910	.....	.....	.....	.....

[a] Commencing April 22. [b] April 5 to 12, inclusive. [c] Commencing May 7. [d] Commencing May 29. [e] Commencing November 15.

[f] First two days in June discharge equaled 2,745 second-feet each day.

[g] The run-off for the period covered by the river height observations only; the discharge given above is for average months and an average year, based upon the records kept. The details may be found in the authorities cited for this station.

Maximum and minimum discharge and average run-off of South Platte River at Deansbury and Platte Canyon for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1887	Sept. —	95	June —	785	0.93	0.12
1888	Oct. —	210	July —	670	.70	.15
1889	Sept. 6	92	May 21	788	.77	.11
1890	Oct. 30	112	July 13	875	.98	.14
1891	Apr. 5	121	June 9	1,495	1.37	.24
1892	Oct. 8	270	June 26	962	1.09	.21
1895	Dec. 26	92	Nov. 19	311	.12	.08
1896	Jan. 25	90	Apr. 28	983	1.22	.09
1897	Jan. 28	67	June 1	1,550	1.15	.17
1899	Dec. 5	10	June 20	2,175	2.16	.21
1900	Feb. 14	41	June 1	2,745	1.36	.27

Discharge measurements made on South Platte River at Deansbury and Platte Canyon.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1895.		*Feet.*	*Sec.-ft.*	
Nov. 30	L. R. Hope	4	197	At Deansbury, station No. 1.
Dec. 1	do	3.20	102	Do.
Dec. 7	do	3.60	160	Do.
Dec. 8	do	3.65	166	Do.
Dec. 14	do	3.80	183	Do.
Dec. 20	do	3.35	135	Do.
1896.				
Jan. 12	L. R. Hope	3.05	94	Do.
Jan. 18	do	3.05	94	Do.
Jan. 27	do	2.90	90	Do.
Feb. 4	do	3.18	116	Do.
Feb. 11	do	3.10	101	Do.
Feb. 19	do	2.97	91	Do.
Feb. 23	do	3.42	144	Do.
Mar. 18	do	3.07	97	Do.
Mar. 20	do	3.75	184	Do.
Mar. 30	do	5.15	372	Do.
Apr. 2	do	4.30	259	Do.
Apr. 13	do	4.85	329	Do.
May 3	do	2.70	557	At Deansbury, station No. 2.
May 26	do	2.55	485	Do.
June 9	do	1.90	314	Do.

Discharge measurements made on South Platte River at Deansbury and Platte Canyon—Continued.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1896.		*Feet.*	*Sec.-ft*	
June 14	L. R. Hope	1.44	235	At Deansbury, station No. 2.
July 6	do	.90	138	Do.
July 24	do	1.66	289	Do.
Aug. 14	do	.73	125	Do.
Aug. 25	do	1.30	205	Do.
Sept. 28	do	1.50	239	Do.
Oct. 10	do	1.42	233	Do.
Oct. 20	do	1.23	193	Do.
Oct. 31	do	1.33	212	Do.
Nov. 10	do	1.27	201	Do.
1897.				
Jan. 8	L. R. Hope	2.75	79	At Deansbury, station No. 1.
Jan. 16	do	2.68	85	Do.
Jan. 22	do	2.56	68	Do.
Jan. 31	do	2.33	56	Do.
Feb. 17	do	2.58	72	Do.
Mar. 1	do	2.75	90	Do.
Mar. 11	do	2.82	103	Do.
Mar. 20	do	2.75	92	Do.
Mar. 27	do	3.40	165	Do.
Apr. 8	do	4.17	261	Do.
Apr. 17	do	4.70	343	Do.
Apr. 22	do	5.80	511	Do.
Apr. 8	do	1.67	261	At Deansbury, station No. 2.
Apr. 17	do	2.02	343	Do.
Apr. 22	do	2.62	511	Do.
Apr. 3	do	3.05	644	Do.
Apr. 9	do	3.50	831	Do.
May 25	do	4.15	1,006	Do.
June 10	do	3.85	985	Do.
July 1	do	3.15	678	Do.
1899.				
Apr. 14	J. E. Field	1.80	559	Do.
May 8	A. L. Fellows	1.50	500	Do.
June 10	do	2.90	1,127	Do.
July 28	do	1.80	633	Do.
Oct. 4	do	.10	146	Do.
1900.				
Mar. 5	A. L. Fellows	-.40	87	Do.
Apr. 18	do	1.55	467	Do.

A. CASTLEWOOD DAM DURING CONSTRUCTION.

B. CASTLEWOOD LAKE AND DAM.

SOUTH PLATTE RIVER AT DENVER.

Attempts have been made at different times to establish and maintain stations at a number of points in the vicinity of Denver, but the only one that has proved of sufficient value to be kept up is the one located at the Fifteenth street bridge, about 1 mile below the post-office. The location is favorable in some respects, as it is just below the mouth of Cherry Creek, upon which the Castlewood dam (see Pl. III) is situated, the junction of Cherry Creek and the South Platte marking the end of district No. 8 and the beginning of district No. 2. It is, moreover, as favorable a location with reference to channel and banks as can be found anywhere below the point at which the river strikes the sandy plains, where it becomes broad and shallow, with a changeable and shifting bottom. Owing, however, to its being located so near the mouth of Cherry Creek, considerable difficulty is experienced through a deposition of bars of sand and gravel, sometimes along the left bank of the river and again along the right bank, so that occasional changes in gage rods and frequent changes in rating tables are necessary. Measurements at this point are necessarily made as often as possible.

The station is principally valuable as giving information concerning the discharge at the head of irrigation district No. 2, so that the division of water among consumers may be regulated by the water commissioner with greater facility. Measurements are made from the bridge, except at low water, when they may be made by wading.[a]

[a] For more detailed information concerning this station see Biennial Reports of State Engineers of Colorado: Fifth, Part I, p. 26, Part II, pl. 12; Sixth, p. 19; Eighth, p. 420; Ninth, p. 330; Tenth, p. 256. Annual Reports U. S. Geological Survey: Eighteenth, Part IV, p. 162; Nineteenth, Part IV, p. 313; Twentieth, Part IV, p. 279; Twenty-first, Part IV, p. 201. Bulletin U. S. Geological Survey No. 140, p. 104. Water-Supply and Irrigation Papers, No. 11, p. 53; No. 15, p. 88; No. 27, pp. 81, 86, 89; No. 37, p. 225; No. 39, p. 448; and No. 49, p. 281. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101, 109, 114.

Discharge of South Platte River at Denver.

[Altitude, 5,183 feet; drainage area, 3,840 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.[a]	Mean run-off.	
									Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	182	95	164	55	204	140	8,608	0.04	0.04
February	.....	198	83	153	196	193	164	9,108	.04	.04
March	.....	225	179	121	409	184	223	13,711	.06	.07
April	.....	301	470	377	466	1,634	649	38,619	.17	.19
May	.....	291	735	1,444	432	4,187	1,418	87,190	.37	.43
June	.....	200	1,026	1,552	821	2,817	1,283	76,344	.33	.37
July	854	164	392	672	637	370	515	31,666	.13	.15
August	742	115	687	328	527	148	424	26,071	.11	.13
September	426	145	270	187	286	123	239	14,222	.06	.07
October	698	111	267	146	109	104	239	14,695	.06	.07
November	456	101	406	131	202	179	246	14,638	.06	.07
December	204	103	217	98	146	178	157	9,653	.04	.04
Mean	563	178	402	448	357	860	475	344,525	.12	1.67
Acre-feet for period recorded[a]	206,070	128,837	291,996	325,006	258,850	632,690	.....	.....	.....	.....

[a] The run-off given is for the period covered by the observations of each year. That given in the vertical columns is for average months and years from all the data obtained. Details for these years may be seen in authorities cited for this station.

Maximum and minimum discharge and total run-off of South Platte River at Denver for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Dec. 23	108	Aug. 2	1,945	1.19	0.14
1896	Oct. 11	27	July 25	758	.62	.05
1897	Feb. 13	16	Aug. 5	2,458	1.426	.105
1898	Dec. 23	50	May 28	2,308	1.58	.12
1899	Jan. 22	42	Aug. 5	1,422	1.257	.093
1900	Oct. 7	51	Apr. 29	5,510	2.92	.22

Discharge measurements made on South Platte River at Denver.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-feet.*
May 7	P. J. Preston		168
July 23	F. Cogswell	5.40	1,490
Aug. 7	P. J. Preston	4.60	876
Aug. 22	do	3.90	447
Nov. 9	do	4.30	430
Nov. 29	do	3.90	303
1896.			
Jan. 6	P. J. Preston	3.60	183
Apr. 8	do	4.50	235
May 29	do	4.90	304
July 1	do	4.33	107
July 25	do	6.10	1,316
Aug. 5	do	4.35	125
Aug. 26	R. A. Sumner	4.80	83
Sept. 11	F. Cogswell	5.10	163
Oct. 30	P. J. Preston	4.70	93
Nov. 9	do	4.75	100
1897.			
Jan. 15	P. J. Preston	4.70	98
Apr. 15	F. Cogswell	5.35	385
May 1	do	5.70	595
May 25	do	5.85	778
June 4	do	6.45	1,311
June 15	do	6.75	1,406
July 13	do	5.60	687
Aug. 5	do	7.45	1,849
Aug. 20	do	5.55	473
Sept. 6	do	4.95	116
Oct. 11	do	5.70	413

Discharge measurements made on South Platte River at Denver—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Apr. 21	A. L. Fellows	5.90	564
July 6	do	6.10	443
Sept. 2	do	5.50	195
Oct. 8	do	5.00	90
Oct. 29	F. Cogswell	5.32	234
1899.			
Apr. 12	A. L. Fellows	6.00	422
May 11	do	6.03	355
June 12	do	6.20	764
July 27	do	5.32	213
Aug. 4	do	6.93	1,200
Sept. 6	do	5.95	288
Oct. 5	do	5.10	100
1900.			
Mar. 6	A. L. Fellows	5.50	244
Apr. 12	do	5.90	377
Apr. 16	do	7.24	1,459
Apr. 20	do	7.10	1,395
Apr. 23	do	8.32	3,516
June 11	do	8.50	3,270
July 25	do	5.45	257
Aug. 7	do	5.56	285
Aug. 29	do	4.90	90
Oct. 20	R. W. Hawley	5.50	226
Oct. 22	do	5.30	161

SOUTH PLATTE RIVER AT ORCHARD.

This station was established November 20, 1895, for the purpose of furnishing data relative to the flow of South Platte River in the winter months and during flood stages, but later was maintained throughout the entire year for the purpose of determining the total discharge. It is situated some distance below all the mountain drainage of the stream and below the territory in which there is the greatest return from seepage. For three years the rod was located in a bend of the river about one-fourth of a mile southwest of the railroad station at Orchard, but later a new rod was placed at the wagon bridge south of the town, and since that time readings have been taken at the latter point, for the reason that it was necessary to make the gagings from the wagon bridge at times of high water. The channel throughout this entire region is broad and shallow, the bottom being sandy and shifting, rendering frequent changes in the rating tables necessary.

The investigations at this point have demonstrated that great amounts of water go to waste, and private capital has been enlisted for the construction of the reservoirs of the South Platte Land, Reservoir and Irrigation Company in the vicinity of Orchard. The reservoirs of this company consist of natural basins located in the plains on each side of the river, all water being diverted from the river to the reservoir sites by means of large canals.[a]

[a] For more detailed information concerning this station see Biennial Reports of State Engineers of Colorado: Eighth, p. 426; Ninth, p. 333; Tenth, p. 261. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 166; Nineteenth, Part IV, p. 315; Twentieth, Part IV, p. 293; Twenty-first, Part IV, p. 203; Bulletin No. 140, p. 112; Water-Supply and Irrigation Papers No. 11, p. 53; No. 15, p. 89; No. 27, pp. 84, 86, and 89; No. 37, p. 226; No. 39, p. 448, and No. 49, p. 282. Also Report on Agriculture by Irrigation, Eleventh Census, pp. 122 and 132.

Discharge of South Platte River at Orchard.

[Altitude, 4 393 feet; drainage area, 12,260 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.	
									Sec.-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	775	631	[a] 1,068	[a] 2,880	[a] 1,634	[a] 1,397	[a] 85,898	[a] 0.11	[a] 0.13
February	.....	[b] 610	557	811	[a] 3,321	[a] 1,268	[a] 1,313	[a] 72,920	[a] .11	[a] .11
March	.....	581	231	574	[a] 2,377	[c] 683	[c] 889	[a] 54,662	[a] .07	[a] .08
April	.....	.....	529	380	[a] 1,325	4,180	[a] 1,603	[a] 95,386	[a] .13	[a] .14
May	.....	.....	898	1,946	465	8,617	2,981	183,294	.23	.26
June	.....	.....	2,637	776	1,198	4,638	2,312	137,574	.19	.21
July	.....	.....	347	173	1,593	171	571	35,110	.05	.06
August	.....	.....	803	40	761	114	429	26,378	.03	.03
September	.....	.....	92	69	45	142	87	5,177	.01	.01
October	.....	.....	303	215	429	431	344	21,151	.03	.03
November	[d] 870	.....	[a] 1,109	811	799	611	840	49,983	.07	.08
December	759	789	[a] 1,232	[a] 2,651	[a] 1,544	614	[a] 1,264	77,720	.10	.12
Mean	814	688	[a] 789	[a] 792	[a] 1,394	[a] 1,925	[a] 1,269	[a] 845,253	[a] .10	[a] 1.26
Acre-feet for period recorded [e]	62,199	148,829	564,500	551,150	1,009,225	1,453,570	.....	.....	.....	.....

[a] The calculations are from the gage heights reported by the observer, but the discharge given for the winter months is probably much too high, owing to ice gorges raising the water on the gage. The winter discharge marked (c) was also probably very much less than the figures would indicate.

[b] February 16 to 29, inclusive.

[d] Commencing November 22.

[e] The run-off per acre-foot given is for that period of each year covered by the observations, the discharge given is for average months and years from all data available. The details for these years may be seen in the authorities cited for this station.

Maximum and minimum discharge and average run-off of South Platte River at Orchard for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 22	818	Dec. 1	1,031	0.095	0.07
1896	Dec. 27	213	Jan. 9	960	.226	.06
1897	July 8	39	June 14	5,160	.851	.064
1898	Apr. 28	10	May 29	3,214	.90	.07
1899	June 12	10	Feb. 27	3,966	1.56	.11
1900	Aug. 16	113	May 2	11,159	2.16	.16

Discharge measurements made on South Platte River at Orchard.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
Nov. 20	P. J. Preston	4.00	829
Dec. 27	do	3.83	667
1896.			
Feb. 19	H. A. Sumner	3.98	669
Oct. 22	P. J. Preston	3.20	240
Dec. 12	do	4.55	550
1897.			
Jan. 18	P. J. Preston	4.14	377
May 28	L. R. Hope	5.00	1,921
June 20	R. S. Sumner	4.68	1,926
June 27	do	3.20	504
July 25	do	3.60	524
Sept. 13	do	2.50	86
Nov. 9	do	4.40	1,299
1898.			
Apr. 24	A. L. Fellows	2.20	71
May 30	do	4.60	3,214
July 9	do	2.25	32
Aug. 9	do	2.25	36
Nov. 6	F. Cogswell	2.80	302
Nov. 17	do	3.15	491
1899.			
Apr. 14	A. L. Fellows	3.20	1,258
May 27	do	2.30	158
Sept. 12	do	2.05	57
Nov. 3	M. D. Williams	2.80	614

Discharge measurements made on South Platte River, at Orchard—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 7	A. L. Fellows	2.85	668
Apr. 21	do	5.00	4,674
July 23	do	1.35	156
Oct. 27	R. W. Hawley	2.70	324

SOUTH PLATTE RIVER AT JULESBURG.

Although no station has been regularly maintained at this point, a number of measurements, which are given in the table below, have been made here at different times. The location is important from the fact that it is near the line between Colorado and Nebraska, so that discharge measurements at this point indicate the flow from the one State into the other. The channel is broad and shallow, the bottom being sandy and shifting. A gage rod was fastened to the wagon bridge 1 mile southeast of Julesburg in the spring of 1900, but no records were kept. Measurements may be made either from the wagon bridge or at low water by wading. The majority of the gagings at this point were made by employees of the State engineer's office in connection with the annual seepage measurements of the South Platte River.[a]

Discharge measurements made on South Platte River, at Julesburg.

[Altitude 3,560 feet.]

Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*
November 5, 1891		43
November 4, 1894		2
November 14, 1895		586
September 4, 1899		2
November 12, 1899		487
March 8, 1900	2.10	2,291
November 2, 1900		76

BEAR CREEK AT MORRISON.

Bear Creek is the first important tributary received by South Platte River after it leaves the mountains. Information concerning the discharge of this stream is important, as it supplies a large proportion of the water furnished to Denver by the Denver Union Water Company.

[a] See also Tenth Biennial Report of the State of Colorado, p. 265. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 131.

storage reservoirs having been provided for this purpose in Marston and Harriman lakes. Nearly the entire flow of this stream is used for the water supply of Denver and for irrigation, there being a scarcity of water along the stream except for the earliest priorities during a large portion of almost every irrigation season. Like all mountain streams, it is subject to sudden and violent rises from sharp and severe storms at its headwaters.[a]

The station was located for some years about the center of the town of Morrison, but in the spring of 1899 it was moved to a point just above Morrison, at the headgate of the Denver Union Water Company's pipe line. The conditions have generally been rather unfavorable to correctness of measurements, as the channel is somewhat changeable, being made up of loose bowlders, and at the dam where the water is diverted into the pipe line gravel bars have formed, changing the natural conditions. Measurements have been made by wading, excepting at the highest stages of the water, when they have been made from the wagon bridge just above the town of Morrison.[b]

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[a] For full description see Hayden's Report of 1875, p. 432.

[b] For further details concerning this station see Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 64, and Part II, Pl. XX; Fifth, Part I, p. 30, and Part II, Pl. XIV; Sixth, pp. 20 and 31; Eighth, p. 454; Ninth, p. 336; Tenth, pp. 223 and 266. Publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 167; Nineteenth, Part IV, p. 317; Twentieth, Part IV, p. 284; Twenty-first, Part IV, p. 204; Bulletin No. 140, p. 106; Water-Supply and Irrigation Papers, No. 11, p. 54; No. 15, p. 90; No. 27, pp. 81 and 86; No. 37, p. 227; No. 39, p. 448, and No. 49, p. 284. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 114.

Discharge of Bear Creek at Morrison.

[Altitude, 5,765 feet; drainage area, 170 square miles.]

Month.	1888.	1889.	1890.	1891.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet. (a)	Mean run-off. Depth in inches.	Mean run-off. Second-feet per square mile.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	31	.....	.....	[b]50	.....	[c]49	.....	.....	[d]84	[e]306	104	6,188	0.68	0.61
May	95	[f]701	63	195	[g]69	51	[f]152	[f]117	103	487	144	8,731	.98	.85
June	100	[h]85	31	289	[i]183	32	175	143	93	379	151	8,985	.99	.89
July	65	49	34	90	136	[j]33	115	150	86	115	87	5,349	.59	.51
August	55	[k]58	24	32	122	[l]53	199	68	104	51	77	4,673	.52	.45
September	30	.....	20	25	69	50	67	45	31	[m]27	40	2,380	.27	.24
October	.....	.....	21	.....	[n]61	35	55	29	[o]21	29	36	2,152	.24	.21
November	.....	.....	17	.....	.....	.....	34	23	.....	16	22	1,309	.14	.13
December	.....	.....	.....	.....	.....	.....	[m]20	.....	.....	.....	20	1,190	.14	.12
Mean [p]	63	73	30	113	107	44	102	82	75	176	76	40,957	4.55	.45
Acre-feet [p]	3,749	4,344	1,785	6,724	6,367	2,618	6,069	4,879	4,463	10,472	.....	.....	.....	.....

[a] The discharge given is for average months, and the total for an average period of nine months, as shown by the observations. Details may be found in the authorities cited for this station.

[b] Commencing April 5.
[c] Commencing April 6.
[d] Commencing April 16.
[e] Commencing April 14.
[f] Commencing May 3.
[g] For May 19 to 31, inclusive.
[h] June 9 to 19, inclusive, is missing.
[i] June 3 to 12, inclusive, is missing.
[j] July 25 to 31, inclusive, is missing.
[k] Ending August 10.
[l] August 1 to 5, inclusive, is missing.
[m] Approximated.
[n] Ending October 5.
[o] Ending October 21.
[p] For period covered.

Maximum and minimum discharge and average run-off of Bear Creek at Morrison for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. —	30	June —	100	0.41	0.37
1889	May 3	18	May 20	195	.48	.43
1890	Nov. 15	15	July 23	75	.20	.18
1891	Sept. 22	12	May 27	622	.73	.66
1895	May 20	41	June 13	274	.70	.63
1896	July 14	9	Apr. 2	86	.29	.26
1897	Nov. 24	5	Aug. 3	385	.67	.60
1898	Nov. 23	20	July 13	2,083	.54	.48
1899	Oct. 21	17	Aug. 4	325	.49	.44
1900	Nov. 23	10	Apr. 29	691	1.15	1.03

Discharge measurements made on Bear Creek at Morrison.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 18	P. J. Preston	0.90	47
June 12	do	2.05	331
July 24	do	1.65	171
Oct. 7	do	1.05	64
1896.			
June 17	P. J. Preston	.75	32
Aug. 4	do	2.90	55
Sept. 19	R. S. Sumner	3.05	80
Oct. 31	P. J. Preston	2.55	16
1897.			
May 20	R. L. Hope	3.60	179
June 13	R. S. Sumner	3.70	209
June 26	do	3.50	162
July 24	do	3.45	131
Sept. 11	F. Cogswell	3.05	55
Oct. 12	do	3.00	52
1899.			
Apr. 15	J. E. Field	3.80	64
May 9	A. L. Fellows	4.25	99
June 6	do	4.25	107
Aug. 5	do	4.98	192
Nov. 14	do	1.35	13

Discharge measurements made on Bear Creek at Morrison—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 9	A. L. Fellows	1.40	17
Apr. 14	do	2.85	47
Apr. 25	do	5.80	367
Aug. 7	do	3.20	63
Sept. 6	do		24

CLEAR CREEK AT FORKSCREEK.

Clear Creek is one of the largest tributaries of South Platte River, issuing from the mountains, and emptying into the main stream about 6 miles below Denver. Like the other streams of this region, it flows for a long distance through a mountainous territory (see Pl. IV, *A*) and then discharges into the plains, where its water is used for irrigation. The establishment of a station at Forkscreek, which is about 12 miles up the canyon, was for the purpose of determining not only the amount of its water that may be available for irrigation and storage, but the amount that may be used for the development of power. The water of Clear Creek is used to such an extent for placer mining and for the development of power for use in stamp mills that the name "Clear Creek" has long since become a misnomer, the stream being anything but clear. After the stream empties into the plains the greater part of the water is used for irrigation, there being comparatively little surplus even during the flood stages.[a]

Measurements were also made in the years 1887 and 1888 at a point below the mouth of the canyon, and estimates were made for the year 1898 by the water commissioner of the Clear Creek water district. The discharges of these years are too unreliable to be incorporated into the table, but they are given by themselves.

Results obtained at this station are not entirely satisfactory, as the channel consists of bowlders and the fall is great, the banks being high and rocky. There is, moreover, no suitable method of crossing the river, the bridges being unsatisfactory, so that most of the measurements have been taken at low-water stages.[b]

[a] For full description of this drainage basin see Hayden's Report, of 1875, p. 432; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 114.

[b] For further details concerning this station see Biennial Reports of State Engineer of Colorado: Fourth, Part I, p. 63, and Part II, Pl. XVIII; Fifth, Part I, p. 18; Sixth, p. 20; Ninth, p. 340; Tenth, pp. 222 and 270. Publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 205; Water-Supply and Irrigation Papers, No. 37, p. 228; No. 39, p. 448 and No. 49, p. 286. Report on Agriculture by Irrigation, Eleventh Census, p. 114.

A. CLEAR CREEK CANYON ABOVE FORKS CREEK.

B. HOME SUPPLY DAM ON BIG THOMPSON CREEK.

Discharge of Clear Creek at Golden.

[In cubic feet per second.]

Year.	Average for month.						
	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1897	621	793	516	304	181	130	.....
1898	285	650	420	120	75	70	57

NOTE.—This table was furnished by W. N. Palmer, water commissioner for the Clear Creek district for 1897 and 1898. The winter discharge is given as about 50 second-feet.

Estimated monthly discharge of Clear Creek at Forkscreek.

[Altitude, 6,892 feet; drainage area, 345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	403	51	180	10,711	0.52	0.58
May 1 to 19	1,202	192	581	35,724	1.68	1.94
June 7 to 30	1,373	775	1,081	64,324	3.13	3.49
July	1,202	614	791	48,637	2.30	2.66
August	692	299	440	27,005	1.28	1.48
September	349	155	214	12,734	0.62	.69
October	155	133	141	8,670	0.41	.47
November	155	32	77	4,582	0.22	.24
Total	.....	.....	.....	212,387	.....	11.55
1900.						
March 10 to 31	75	44	60	2,619	0.17	.20
April	403	58	178	10,592	0.52	.58
May	1,259	367	789	48,514	2.29	2.64
June	1,259	714	968	57,601	2.80	3.12
July	719	235	378	23,242	1.10	1.27
August	235	84	137	8,424	0.40	.46
September	75	44	58	3,451	0.17	.19
October	75	51	58	3,566	0.17	.20
November	58	51	52	3,094	0.15	.17
Total	.....	.....	.....	161,103	.....	8.83

Discharge measurements made on Clear Creek at Forkscreek.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Mar. 24	J. E. Field	1.50	52
Apr. 20	do	2.10	155
May 10	A. L. Fellows	2.75	365
June 7	do	3.70	779
Aug. 12	do	3.08	449
Nov. 15	do	1.70	67
1900.			
Mar. 10	do	1.60	55
Apr. 13	do	1.70	73
Apr. 24	do	2.60	290
Aug. 27	do	1.78	130

ST. VRAIN CREEK NEAR LYONS.

St. Vrain Creek and its tributaries receive their supply of water from the eastern slope of that portion of the Front Range lying between Longs Peak and James Peak, a distance of about 30 miles. The general trend of the drainage is northeastward, the St. Vrain flowing at last into South Platte River about 6 miles below the town of Platteville. The principal tributaries of the St. Vrain are the North and South Forks and the Boulder, the South Boulder being an important branch of the latter. The areas drained by the upper portions of these streams are all alike mountainous, the streams flowing through deep and rugged canyons, where the water can be used only for the development of power and for placer mining; but upon leaving the foothills each one of them emerges into a broad and nearly level valley where farming by irrigation is extensively practiced.[a]

Three stations have been maintained upon the St. Vrain and its tributaries, one located at a point about one-half of a mile east of Lyons, upon the St. Vrain, one at a point at the mouth of the canyon of the Boulder, a mile above the town of Boulder, and one at a point in the mouth of the South Boulder Canyon about 3 miles west of Marshall.

Records have been kept of the gage heights at the Lyons station since April, 1888, except during the years 1893 and 1894, when very little hydrographic work was done in Colorado. A number of changes in the location and position of the gage rod have been necessary, but these have not affected the value of the tables, the station being always practically the same. As maintained at the present time the station is opposite the Tower Hotel. Most of the measurements are made by

[a] For full description of this basin see Hayden's Report of 1875, p. 436. Also Report on Agriculture by Irrigation, Eleventh Census, p. 103.

wading, but at high water they are made from a bridge located about one-quarter of a mile below the station. The channel is favorable to good results, lying in small bowlders and cobblestones, and the banks are so high that overflow is improbable. The table of discharge includes the amount carried by the Supply ditch, which is taken out above the station but of which records were also kept.[a]

[a] For more detailed data concerning this station see Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 63, and Part II, Pl. XIX; Fifth, Part I, pp. 18 and 28, Part II, Pl. XIII; Sixth, pp. 20 and 28; Eighth, p. 436; Ninth, p. 348; Tenth, pp. 213 and 280. See also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 172; Nineteenth, Part IV, p. 320; Twentieth, Part IV, p. 285; Twenty-first, Part IV, p. 208; Bulletin No. 140, p. 109; Water-Supply and Irrigation Papers, No. 11, p. 55; No. 15, p. 93; No. 27, pp. 83, 86, and 89; No. 37, p. 232; No. 39, p. 448; and No. 49, p. 288. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

Discharge of St. Vrain Creek at Lyons.

[Drainage area, 209 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.[c]	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	72	.....	.....	165	.....	.....	96	.....	.....	222	361	183	10,889	0.88	0.98
May	156	[a] 465	[b] 376	629	([c])	.....	259	[d] 571	243	300	657	406	24,964	1.94	2.24
June	320	371	436	1,046	856	[e] 790	363	766	483	829	709	634	37,726	3.03	3.38
July	208	197	292	516	587	469	225	506	261	734	290	390	23,980	1.87	2.16
August	133	102	179	151	155	243	167	303	113	330	107	180	11,068	.86	.99
September	56	44	66	96	89	98	139	127	68	95	72	86	5,117	.41	.46
October	50	39	45	.....	65	197	65	50	22	44	49	63	3,874	.30	.35
November	.....	.....	30	.....	.....	.....	37	.....	20	24	31	28	1,666	.13	.14
Mean[f]	142	203	203	434	350	359	169	387	173	322	285	246	119,284	1.18	10.70
Acre-feet[f]	60,415	66,495	80,600	159,380	106,182	100,392	81,740	140,544	73,402	155,916	138,304	.....	.....	.....	.....

[a] May 20 to 31 inclusive.

[b] May 15 to 31 inclusive.

[c] Stations were maintained upon both forks of the St. Vrain in 1892. The monthly averages given are the sums for the two forks. The average for May 29 to 31 on South Fork was 373 second-feet and from May 26 to 31 on North Fork was 231 second-feet.

[d] Commencing May 2.

[e] Commencing June 13.

[f] For period covered by observations.

Maximum and minimum discharge and average run-off of St. Vrain Creek at Lyons for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	June —	[a] 320	Oct. —	[a] 50	0.75	0.68
1889	May 28	548	Oct. 13	26	1.08	.97
1890	June 2	675	Nov. 15	18	1.08	.97
1891	May 27	1,397	Apr. 5	31	2.32	2.08
1892	June 24	1,480	Oct. 28	53	1.86	1.67
1895	June 16	1,127	Sept. 14	80	1.92	1.72
1896	May 30	666	Oct. 26	21	.90	.81
1897	June 11	1,052	Nov. 16	31	2.06	1.85
1898	June 17	637	Nov. 26	21	.91	.82
1899	June 20	1,275	Nov. 11	16	1.72	1.54
1900	Apr. 29	918	Mar. 17	10	1.52	1.36

[a] May 20 to 31 inclusive.

Discharge measurements made on St. Vrain Creek at Lyons.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-feet.*
May 11	P. J. Preston	1.65	260
July 20	do	3.40	336
Oct. 2	do	2.10	65
1896.			
June 6	P. J. Preston	3.57	389
July 29	do	2.70	189
Sept. 22	R. S. Sumner	2.50	110
Oct. 14	P. J. Preston	2.22	53
1897.			
May 25	L. R. Hope	4.15	659
June 17	R. S. Sumner	4.40	713
June 28	do	3.70	551
July 20	do	3.10	379
Sept. 15	F. Cogswell	2.10	115
Nov. 10	do	1.75	54
1898.			
May 27	A. L. Fellows	2.80	256
July 12	do	3.10	308
Aug. 5	do	2.20	73
Oct. 12	do	1.85	20

Discharge measurements made on St. Vrain Creek at Lyons—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-feet.*
Apr. 18	J. E. Field	3.00	217
May 5	A. L. Fellows	2.75	137
June 14	.....do	4.15	825
Aug. 9	.....do	3.20	263
Oct. 7	.....do	2.10	37
1900.			
Mar. 13	A. L. Fellows	2.06	35
Apr. 27	.....do	3.68	513
July 27	.....do	2.70	193

BOULDER CREEK NEAR BOULDER.

The general nature of Boulder Creek, which is one of the tributaries of the St. Vrain, has already been noted in the description of the main stream.[a]

The gaging station is located 1½ miles above the town of Boulder, in the mouth of the canyon. There are two small irrigation ditches above the station, but the amount of water diverted does not exceed 5 or 6 second-feet, and may therefore be disregarded. The channel of the stream consists of large bowlders throughout its entire course, and it is therefore difficult to make accurate measurements. Gagings are usually made by wading, but may be made from a wagon bridge just above the gage rod at high water. The normal flow is entirely used for irrigation, but during the flood season a large proportion goes to waste. Fillings have, however, been made upon a number of reservoir sites in this drainage basin, by means of which most of the surplus water might be stored.[b]

[a] For a description of this drainage basin, see Hayden's Report of 1875, p. 435. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

[b] Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 64, and Part II, Pl. XXI; Fifth, Part I, pp. 18 and 32, and Part II, Pl. XV; Sixth, pp. 21 and 33; Eighth, p. 442; Ninth, p. 345; Tenth, pp. 224 and 277. Also publications U. S. Geological Survey: Annual Reports, Eighteenth, Part IV, p. 171; Nineteenth, Part IV, p. 319; Twentieth, Part IV, p. 286; Twenty-first, Part IV, pp. 207-208; Bulletin No. 140, p. 108; Water-Supply and Irrigation Papers, No. 11, p. 55; No. 15, p. 92; No. 27, pp. 82, 86, and 89; No. 37, p. 248; No. 49, p. 287. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

Discharge of Boulder Creek at Boulder.

[Altitude, 5,347 feet; drainage area, 179 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	81	.....	.....	.....	.....	.....	80	.....	.....	117	.....	93	5,534	0.52	0.58
May	164	[a] 676	[b] 287	[c] 327	[d] 336	[e] 316	240	323	233	353	625	353	21,705	1.97	2.27
June	261	565	341	427	447	502	264	458	447	663	640	456	27,134	2.55	2.84
July	210	277	258	240	372	355	150	339	213	577	255	295	18,139	1.65	1.90
August	157	97	[f] 173	116	148	205	88	213	62	265	94	147	9,039	0.82	0.94
September	80	34	56	[g] 61	47	86	73	83	30	87	54	63	3,749	0.35	0.39
October	60	36	[h] 33	.....	43	44	33	47	8	39	33	38	2,337	0.21	0.24
November	.....	.....	[i] 26	.....	.....	.....	.....	38	40	24	.....	32	1,904	0.12	0.13
Mean[j]	145	281	168	234	232	251	133	214	148	266	284	185	89,541	1.03	9.29
Acre-feet[j]	61,632	98,589	59,607	58,464	74,520	85,158	56,496	90,736	62,916	128,832	103,592	.....	.....	.....	.....

[a] Commencing May 8.
[b] Commencing May 13.
[c] Commencing May 18.
[d] Commencing May 23.
[e] Commencing May 14.
[f] August 12 to 14 missing.
[g] Ending September 20.
[h] October 16 to 19 missing.
[i] November 3 to 9, inclusive.
[j] For period covered by records.

Maximum and minimum discharge and average run-off of Boulder Creek at Boulder for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-feet		*Sec.-feet.*		
1888	April —	25	June —	350	0.90	0.81
1889	Sept. 20	16	May 31	785	1.75	1.57
1890	Nov. 7	23	Aug. 4	1,200	1.03	0.93
1891	Sept. 16	54	June 8	540	1.46	1.31
1892	Oct. 19	27	June 23	646	1.45	1.30
1895	Oct. 29	5	June 3	750	1.56	1.40
1896	Apr. 3	7	May 30	809	0.82	0.74
1897	Nov. 16	23	June 10	745	1.34	1.20
1898	Nov. 30	3	June 18	560	1.36	1.22
1899	Nov. 29	13	July 2	847	1.66	1.49
1900	Oct. 31	7	June 1	801	1.77	1.59

[a] The run-off given is the amount for that part of each year covered by the records and for an average month of thirty days, at the rate given as the mean for the period covered.

Discharge measurements made on Boulder Creek near Boulder.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
July 17	P. J. Preston	1.90	317
Oct. 13	do	.50	36
1896.			
July 2	P. J. Preston	1.30	139
July 30	do	1.10	110
Sept. 23	R. S. Sumner	.80	69
Oct. 16	P. J. Preston	.50	35
1897.			
May 21	L. R. Hope	2.15	442
July 26	R. S. Sumner	1.75	298
Aug. 12	F. Cogswell	1.55	224
Oct. 13	do	.55	48
1898.			
Apr. 17	A. L. Fellows	.78	69
May 28	do	1.85	367
July 16	J. E. Field	1.50	266
Aug. 3	A. L. Fellows	.86	62
Oct. 11	do	.28	12

Discharge measurements made on Boulder Creek near Boulder—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 21	J. E. Field	1.00	84
May 6	A. L. Fellows	1.20	134
June 15	do	2.50	642
Aug. 10	do	1.70	276
Otc. 20	do	.50	36
1900.			
Apr. 28	A. L. Fellows	2.10	483
July 27	do	1.40	220
Aug. 28	do	.62	49

SOUTH BOULDER CREEK AT MARSHALL.

South Boulder Creek is a tributary of the Boulder, and its drainage basin lies north of and adjoins that of Clear Creek.[a] The station has been maintained for each irrigation season since April, 1888, except during 1893 and 1894. The rod consists of an inclined timber on the north bank of the stream, near the house of C. E. Barber. Two ditches take their water supply from the stream at points above the station, these being the South Boulder and Coal Creek ditch and the Community ditch, and their discharges are added to the discharge as found at the station, so as to give the total run-off of the basin. The channel of the stream is rocky and full of bowlders, but does not change materially. Gagings are usually made by wading, but at high water they may be made from the foot bridge just above the rod.[b]

[a] For description see Hayden's Report of 1875, p. 436. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

[b] For more detailed data concerning this station see Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 64, and Part II, Pl. XXIII; Fifth, Part I, p. 36. and Part II, Pl. XVII; Sixth, pp. 21 and 36; Eighth, p. 448; Ninth, p. 341; Tenth, pp. 225 and 273. Also publications of U. S. Geological Survey, Eighteenth Annual Report, Part IV, p. 169; Nineteenth, Part IV, p. 318; Twentieth, Part IV, p. 287; Twenty-first, Part IV, p. 206; Bulletin No. 140, p. 107; Water-Supply and Irrigation Papers, No. 11, p. 54; No. 15, p. 91; No. 27, pp. 82, 86, and 89; No. 37, p. 229, and No. 49, p. 286. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell. p. 103.

Discharge of South Boulder Creek at Marshall.

[Altitude, 5,498 feet; drainage area, 125 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	100	.....	.....	58	.....	.....	72	.....	.....	123	.....	88	5,236	0.70	0.78
May	135	[b] 475	[c] 313	366	[d] 237	[e] 288	232	[f] 332	208	332	.....	292	17,954	2.34	2.70
June	.....	335	349	356	374	592	208	458	325	539	356	371	22,076	2.97	3.31
July	130	152	143	140	232	243	75	235	138	319	93	173	10,637	1.38	1.59
August	98	39	64	45	62	120	43	129	42	121	29	72	4,427	.58	.67
September	40	21	39	20	21	39	37	43	22	35	9	30	1,785	.24	.27
October	.....	20	[g] 31	[h] 19	18	38	23	39	20	.....	.....	26	1,599	.21	.24
November	.....	.....	.....	.....	.....	.....	.....	35	18	.....	.....	26	1,547	.21	.23
Mean[i]	115	174	157	143	157	220	99	182	110	245	121	135	65,261	1.08	9.79
Acre-feet[i]	41,724	54,855	52,878	52,824	53,492	74,188	41,947	76,893	46,652	88,938	29,280	.....	.....	.....	.....

[a] The run-off is for average months, and the total for an average period of eight months as shown by the observations. Details may be found in the authorities cited for this station.

[b] Commencing May 26.
[c] Commencing May 9.
[d] Commencing May 13.
[e] Commencing May 15.
[f] Commencing May 2.
[g] Ending October 25.
[h] Ending October 3.
[i] For period covered by the observations.

Maximum and minimum discharge and average run-off of South Boulder Creek at Marshall for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. —	30	June —	225	1.02	0.92
1889	Oct. 12	15	May 31	560	1.55	1.39
1890	Sept. 20	19	May 28	542	1.41	1.26
1891	Sept. 19	15	May 17	565	1.27	1.14
1892	Oct. 13	15	June 24	561	1.41	1.26
1895	Oct. 1	14	June 3	1,090	1.96	1.76
1896	Oct. 6	18	May 30	603	.88	.79
1897	Nov. 7	18	June 11	595	1.63	1.46
1898	Nov. 18	9	June 17	444	.98	.88
1899	Sept. 21	9	June 21	663	2.19	1.96
1900	Sept. 16	5	June 2	582	1.08	.94

Discharge measurements made on South Boulder Creek at Marshall.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 14	P. J. Preston	2.00	164
July 18	.....do	2.00	195
Oct. 10	.....do	1.05	42
1896.			
July 3	P. J. Preston	1.50	88
Aug. 8	.....do	0.96	27
Sept. 24	R. S. Sumner	1.00	31
Oct. 17	R. J. Preston	0.90	24
1897.			
May 22	L. R. Hope	2.45	348
June 19	R. S. Sumner	2.60	363
June 25	.....do	2.50	370
July 27	.....do	1.65	122
Aug. 13	F. Cogswell	1.55	116
Oct. 14	.....do	0.82	14
1898.			
Apr. 23	A. L. Fellows	1.35	72
May 29	.....do	2.29	274
July 11	.....do	1.70	130
Aug. 6	.....do	1.15	47
Oct. 10	.....do	0.55	2

Discharge measurements made on South Boulder Creek at Marshall.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 22	J. E. Field	1.70	115
May 6	A. L. Fellows	1.55	96
June 15	.....do	2.80	451
Aug. 10	.....do	1.60	109
Oct. 10	.....do	0.70	7
1900.			
July 28	A. L. Fellows	1.40	35
Aug. 28	.....do	1.10	10

BIG THOMPSON CREEK AT ARKINS.

This stream drains considerable territory north of Longs Peak, and is one of the largest tributaries of the South Platte, into which it flows about 4 miles above the town of Evans. The Little Thompson is an important tributary of the Big Thompson, and the country drained by these two streams forms irrigation district No. 4 (see Pl. IV, *B*). The two streams come together a short distance above where their combined waters enter the South Platte.[a]

Records were begun upon this stream in April, 1888, and have been maintained for a portion of each year since that time, except in the years 1893 and 1894. The location of the station has been changed several times, having been below both the Handy and the Home Supply ditches a portion of the time and above the Home Supply and below the Handy at other times. At present it is located at the upper point, so that only the waters carried by the Handy ditch need to be added to give the total run-off of the basin. The amounts given in the tables are for the combined flow. Irrigation is practiced on a small scale about 20 miles above the station also, but to such a limited extent that it may be disregarded.[b]

[a] For description see Hayden's Report for 1875, p. 437; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 116–119.

[b] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Second, p. 6; Fourth, Part I, p. 64, and Part II, Pl. XXII; Fifth, Part I, pp. 18 and 34, and Part II, Pl. IX; Sixth, pp. 21 and 34; Eighth, p. 430; Ninth, pp. 310 and 333; Tenth, pp. 215, 216 and 284. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 174, Nineteenth, Part IV, p. 321; Twentieth, Part IV, p. 288; Twenty-first, Part IV, p. 209; Bulletin No. 140, p. 110; Water-Supply and Irrigation Papers, No. 11, p. 56, No. 15, p. 94; No. 27, pp. 83, 86, and 89; No. 37, p. 233; No. 39, p. 448; and No. 49, p. 290. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 116–119.

Discharge of Big Thompson Creek at Arkins.

[Altitude, 5,255 feet; drainage area, 305 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	62	.....	.....	.....	.....	.....	.....	.....	.....	156	432	217	12,912	0.71	0.79
May	132	[b] 359	[c] 436	.....	[d] 312	[e] 482	295	590	231	353	1,432	462	28,407	1.51	1.74
June	458	382	530	[f] 817	704	943	363	679	499	1,037	1,497	719	42,783	2.36	2.64
July	275	200	454	383	498	683	259	379	317	766	379	418	25,702	1.37	1.58
August	190	89	393	159	150	441	172	196	112	316	149	215	13,220	.70	.81
September	75	49	151	95	49	194	161	71	57	102	87	99	5,891	.32	.36
October	46	46	67	.....	.....	121	96	54	23	64	.....	65	3,997	.21	.24
November	.....	.....	[g] 83	.....	.....	.....	.....	54	18	.....	.....	52	3,094	.17	.19
Mean [h]	177	188	302	364	343	477	224	289	180	399	663	281	136,006	.92	8.35
Acre-feet [h]	75,114	61,545	115,008	85,918	100,520	156,090	81,696	122,622	76,398	169,274	240,645	.....	.....	.....	.....

[a] The run-off is for average months and the total for an average period of eight months as shown by the observation. Details may be found in the authorities cited.
[b] Commencing May 20.
[c] Commencing May 8.
[d] Commencing May 15.
[e] Commencing May 20.
[f] Commencing June 4.
[g] To November 15, inclusive.
[h] For period covered by observations.

Maximum and minimum discharge and average run-off of Big Thompson Creek at Arkins for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Apr. 3	30	June 16	862	0.64	0.58
1889	Oct. 2	28	May 31	546	.69	.62
1890	Oct. 7	51	July 21	1,603	1.10	.99
1891	Sept. 17	69	June 25	1,182	1.33	1.19
1892	Sept. 29	39	June 21	1,195	1.25	1.12
1895	Oct. 2	58	June 2	1,102	1.74	1.56
1896	Oct. 26	76	May 30	1,200	.81	.73
1897	Nov. 18	54	June 11	1,040	1.04	.94
1898	Oct. 24	14	June 24	722	.65	.59
1899	Apr. 9	25	June 21	1,852	1.46	1.31
1900	Apr. 2	30	May 30	2,223	2.42	2.17

[a] The run-off given is the amount for that part of each year covered by the records and for an average month of thirty days at the rate given as the mean for the period covered.

Discharge measurements made on Big Thompson Creek at Arkins.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 9	P. J. Preston	1.25	260
July 19	do	1.90	499
Oct. 1	do	.45	42
1896.			
June 1	P. J. Preston	1.70	403
July 28	do	1.50	286
Oct. 15	do	.80	74
1897.			
May 26	L. R. Hope	2.45	804
June 18	R. S. Sumner	1.60	400
June 27	do	1.50	409
July 21	do	1.20	214
Sept. 16	F. Cogswell	.60	61
Nov. 11	do	.65	79
1898.			
May 26	A. L. Fellows	1.25	263
July 13	do	1.60	444
Aug. 4	do	.70	87
Oct. 14	do	.40	30

Discharge measurements made on Big Thompson Creek at Arkins—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 17	J. E. Field	0.90	143
May 4	A. L. Fellows	.97	173
June 13	do	2.55	941
Aug. 8	do	1.73	406
Oct. 6	do	.50	34
1900.			
Apr. 26	A. L. Fellows	1.91	512
July 26	do	1.35	322

CACHE LA POUDRE RIVER AT FORT COLLINS.

This stream is the largest and the northernmost of the tributaries discharging from the east front of the Rocky Mountains into the South Platte. During the irrigation season its discharge is augmented by the supply diverted from the headwaters of the Laramie River, which heads immediately west of the headwaters of the Cache la Poudre, the diversion being made through a canal known as the Skyline canal, already mentioned (p. 21). Measurements of the discharge of the Cache la Poudre Basin therefore include some of the Laramie waters. As is the case with other streams of this region, the normal flow is almost entirely consumed for irrigation, and even the greater part of the flood waters is stored for late use. The earliest and most thorough irrigation of the State is carried on along this stream.[a] The station was established in 1884 at a point about 15 miles above Fort Collins, and has been maintained ever since that time under the direction of Prof. L. G. Carpenter, of the Colorado State Agricultural College.[b]

The following tables are compiled from records published from time to time by Professor Carpenter, the first table showing the normal discharge as calculated by him for the irrigating season, and the second giving a summary of discharge for the entire time. The results are to a certain extent misleading, as additions have been made to the normal discharge of the stream from year to year through the Skyline canal, taking its water from the headwaters of the Laramie

[a] Water-Supply and Irrigation Paper No. 9 and Department of Agriculture Bulletin No. 92.

[b] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Second, p. 6 and Appendix B; Third, pp. 5 and 62; Fourth, Part I, p. 61, and Part II, Pl. IX; Fifth, Part I, pp. 17 and 22; Sixth, pp. 19 and 22; Seventh, p. 172; Ninth, p. 356; Tenth, p. 288. Also, publications U. S. Geological Survey: Thirteenth Annual Report, Part III, p. 94; Twentieth, Part IV, p. 290; Bulletin No. 131, p. 30; No. 140, p. 112; Water-Supply and Irrigation Papers, No. 9, p. 16; No. 37, p. 235, and No. 49, p. 291. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

River, and this increase is not considered in the tables. In computing the average monthly discharge only those months are included for which the record is complete, or at least estimated:

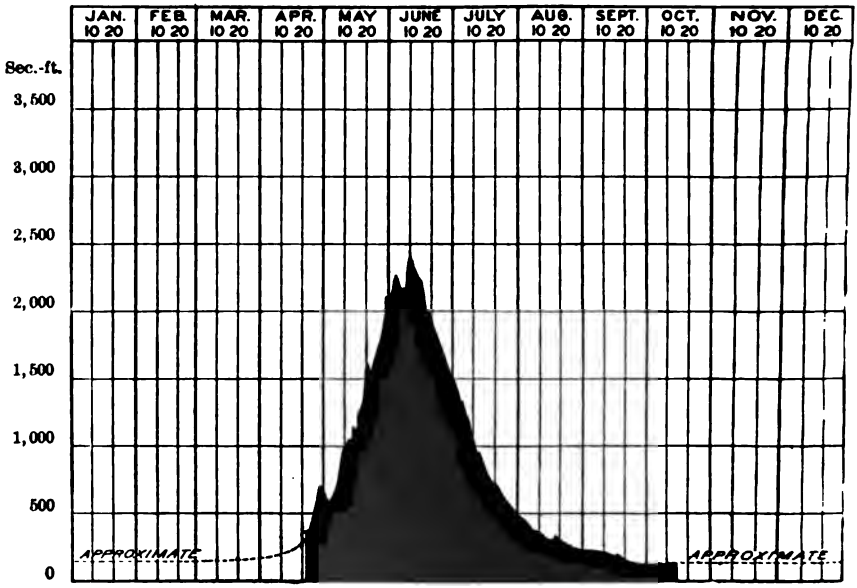

Fig. 1.—Normal discharge of Cache la Poudre River.

Normal discharge of Cache la Poudre River at Fort Collins for the years 1894 to 1900, inclusive.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1	.....	589	2,052	1,426	490	245	147
2	.....	597	2,120	1,399	485	238	137
3	.....	611	2,250	1,328	479	228	133
4	.....	634	2,207	1,290	469	[a] 225	137
5	.....	686	2,108	1,213	438	[a] 222	133
6	.....	729	2,149	1,152	[a] 426	[a] 219	131
7	.....	784	2,136	1,154	414	[a] 216	132
8	.....	842	2,165	1,118	383	[a] 213	133
9	.....	916	2,268	1,069	395	[a] 210	130
10	.....	974	2,385	1,029	398	[a] 207	139
11	.....	999	2,319	954	374	204	129
12	.....	1,024	2,271	965	358	189	129
13	.....	1,012	2,227	951	339	182	132
14	.....	1,046	2,188	871	338	170	130
15	.....	1,109	2,171	856	324	166	127
16	.....	1,232	2,123	814	338	168	.....
17	.....	1,240	2,038	794	325	161	.....
18	.....	1,259	1,959	774	387	154	.....
19	.....	1,311	2,005	737	333	151	.....
20	.....	1,446	1,913	694	317	146	.....
21	.....	1,625	1,966	704	306	144	.....
22	.....	1,547	1,881	650	299	140	.....
23	.....	1,534	1,810	611	291	139	.....
24	367	1,625	1,783	[a] 597	284	144	.....
25	406	1,720	1,755	[a] 583	280	148	.....
26	446	1,804	1,741	[a] 569	262	147	.....
27	541	1,890	1,633	[a] 555	251	148	.....
28	607	1,985	1,619	[a] 542	252	145	.....
29	706	1,980	1,561	[a] 529	251	143	.....
30	651	2,046	1,472	[a] 515	240	141	.....
31	.....	2,028	.....	502	247	.....	.....

[a] Interpolated.

Discharge of Cache la Poudre River at Fort Collins for the years 1884 to 1900, inclusive.

[Altitude, 4,994 feet; drainage area, 1,060 square miles.]

Month.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	.....	.....	.....	.....	151	82	92	64	.....	.....	[a] 90	.....	.....	.....	.....	.....	96	5,903	0.09	0.10
February	.....	.....	.....	.....	.....	106	79	79	179	.....	.....	[a] 90	.....	.....	.....	.....	.....	95	5,464	.09	.09
March	67	.....	.....	.....	.....	46	85	59	80	.....	.....	[a] 90	.....	.....	.....	.....	.....	72	4,427	.07	.08
April	219	[b] 447	[d] 405	[a] 200	181	113	200	144	[a] 100	.....	.....	[a] 390	.....	.....	.....	.....	[c] 1,376	193	11,484	.18	.20
May	2,537	1,419	1,309	[ac] 1,822	483	649	1,044	1,221	[a] 250	[b] 762	[b] 1,436	[ac] 1,216	.....	[a] 2,052	[a] 649	[a] 1,207	2,808	1,302	80,057	1.23	.42
June	4,812	2,910	1,875	[ac] 1,401	1,113	1,338	1,280	1,900	1,512	[b] 1,815	2,063	[a] 2,382	[c] 774	1,731	1,309	2,632	2,942	2,128	126,625	2.01	2.24
July	2,144	1,857	717	735	420	514	649	541	741	617	833	1,117	458	749	478	1,441	721	867	53,310	.82	.94
August	792	656	338	307	213	187	287	228	[a] 200	[b] 235	339	495	272	[a] 352	[a] 147	557	265	352	21,644	.33	.38
September	305	273	185	175	109	67	103	138	.....	.....	164	[a] 219	[a] 273	[a] 177	[a] 78	212	149	175	10,413	.16	.18
October	.....	1,203	129	[a] 120	[a] 90	69	80	118	.....	.....	105	[a] 160	.....	.....	[a] 59	110	[c] 132	204	12,543	.19	.22
November	.....	.....	.....	.....	.....	88	61	83	.....	.....	[b] 95	[a] 110	.....	.....	.....	.....	.....	86	5,117	.08	.09
December	.....	.....	.....	.....	.....	64	70	79	.....	.....	.....	[a] 90	.....	.....	.....	.....	.....	76	4,673	.07	.08
Mean [i]	1,761	1,196	747	720	400	482	567	671	758	811	804	914	520	798	451	1,027	1,266	471	341,660	.44	6.02
Acre-feet [i]	660,177	448,308	279,909	269,892	149,877	180,684	212,625	251,559	[e] 168,709	[f] 194,040	301,403	342,657	195,048	297,108	168,966	374,808	457,002	.....	.....	.....	.....

[a] Estimated or interpolated in part.
[b] Between 20 and 31 days.
[c] Between 10 and 20 days.
[d] Less than 10 days.
[e] From May 17 to September 6, inclusive.
[f] From May 10 to September 6, inclusive.
[g] From May 1 to October 31, inclusive.
[h] From April 18 to October 16, inclusive.

[i] The mean and the run-off in acre-feet given is the amount for 27 weeks from April 26 to November 1, excepting where otherwise stated in the notes, and the corresponding amount for an average month of thirty days at the rate given as the mean for the period covered, while the discharge is for average months and the total for an average year as derived from the observations for all complete months, parts of months not being included in this average, although estimated entire months are.

[j] Details may be found in the authorities cited.

SKYLINE CANAL, NEAR GREELEY.

Maximum and minimum discharge and average run-off of Cache la Poudre River at Fort Collins for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1884	Mar. 22	30	June 28	5,611	1.85	1.66
1885	Oct. 5	220	June 3	3,815	1.26	1.13
1886	Oct. 13	110	May 29	2,666	.83	.75
1887	Sept. 18	110	June 7	2,500	.75	.68
1888	Sept. 19	90	June 15	1,550	.43	.38
1889	Dec. 17	33	June 1	1,960	.50	.45
1890	Nov. 16	39	June 2	1,804	.59	.53
1891	Mar. 31	32	June 10	3,600	.70	.63
1892	Mar. 17	40	June 21	2,535	.79	.71
1893	Aug. 31	151	June 12	2,949	.84	.76
1894	Nov. 17	42	June 6	3,672	.84	.76
1895	Sept. 18	174	June 10	3,429	.95	.86
1896	Aug. 18	192	May 30	2,771	.55	.49
1897	Oct. 1	121	May 24	3,155	.83	.75
1898	Oct. 1	35	June 17	1,699	.48	.43
1899	Oct. 7	92	June 21	3,968	1.08	.97
1900	Sept. 20	113	May 29	4,560	1.33	1.19

LARAMIE RIVER AT WOODS, WYO.

This stream, already briefly described on pages 21 and 55, rises in North Park in Northern Colorado, and flows northerly into Wyoming. There is little irrigation from Laramie River in Colorado, except that a portion of the supply of the Cache la Poudre district is supplied from this source, as already mentioned on pages 21 and 55 (see Pl. V).

The data for this station is published through the courtesy of Mr. A. J. Parshall, deputy State engineer of Wyoming.[a]

[a] For more detailed information, see publications U. S. Geological Survey, Eighteenth Annual Report, Part IV, p. 142; Nineteenth, Part IV, p. 300; Twentieth, Part IV, p. 274; Twenty-first, Part IV, p. 192; Bulletin, No. 131, p. 28; No. 140, p. 95; Water-Supply and Irrigation Papers, No. 11, p. 50; No. 15, p. 81; No. 27, pp. 78, 86, and 88; No. 37, p. 214; No. 39, p. 447, and No. 49, p. 273. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 251.

Discharge of Laramie River at Woods, Wyo.

[Drainage area, 435 miles.]

Month.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b] 200	128	129	571	125	231	13,745	0.53	0.59
May	619	1,964	636	1,284	1,940	1,288	79,196	2.96	3.41
June	465	1,564	969	3,221	1,776	1,599	95,147	3.68	4.09
July	127	266	89	1,253	111	369	22,689	.85	.98
August	94	93	44	191	50	94	5,780	.22	.25
September	116	65	40	56	44	64	3,808	.15	.17
October	[b] 120	[b] 60	[b] 45	65	.....	73	4,489	.17	.20
November	.....	[b] 65	[b] 40	[b] 70	.....	58	3,451	.13	.14
Mean	249	526	249	839	674	472	228,305	1.09	9.83
Acre-feet for period recorded	105,716	254,736	120,536	406,016	243,271	.....	.....	.....	.....

[a] The run-off given is for that part of each year covered by the observations (and estimates) given and for a thirty-day month at the rate given as the mean for the whole period covered, while the discharge given is for average months, and the total for an average eight months from April to November, inclusive, as calculated from the beservations (and estimates). Details may be found in the authorities cited.

[b] Approximate for the month.

Maximum and minimum discharge and average run-off of Laramie River at Woods, Wyo., for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1896	Aug.	49	May	2,166	0.63	0.57
1897	Apr.	48	May	3,435	1.35	1.21
1898	Sept.	40	May	1,572	.63	.57
1899	Oct. 1	45	June 25	4,502	2.15	1.93
1900	Sept. 1	40	May 31	3,995	1.73	1.55

Discharge measurements made on Laramie River at Woods, Wyo.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Sept. 27	W. M. Gilcrest		27
Sept. 28	do		57
Nov. 3	do		80
1895.			
May 24	W. M. Gilcrest	2.80	1,129
Oct. 23	do	0.80	49
1896.			
Apr. 20	W. M. Gilcrest	0.85	75
May 25	do	2.40	797
June 16	do	1.75	350
June 27	Elwood Mead	1.25	198
Aug. 19	W. M. Gilcrest	0.85	81
Aug. 30	do	0.80	75
Oct. 2	C. T. Johnston	1.00	121
1897.			
Apr. 10	C. T. Johnston	0.70	69
May 12	do	2.30	1,110
May 25	do	4.10	3,538
June 1	do	3.60	2,509
June 2	do	3.75	2,651
June 14	do	2.65	1,432
June 26	do	2.00	707
June 27	do	2.00	706
1898.			
Apr. 30	C. T. Johnston	1.40	362
May 22	do	2.00	758
June 4	do	[a] 2.30	1,017
June 4	do	[b] 2.40	1,123
June 5	do	2.10	823

Discharge measurements made on Laramie River at Woods, Wyo.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
May 26	A. J. Parshall	3.30	2,598
June 8	.....do	3.10	2,319
June 21	.....do	4.40	4,145
July 6	.....do	2.80	2,194
1900.			
May 4	A. J. Parshall	1.60	460

[a] At 6 a. m. [b] At 7.30 p. m.

MISCELLANEOUS MEASUREMENTS.

The following table of miscellaneous measurements upon South Platte River and its tributaries is compiled from the Colorado State Engineers' Biennial Reports, and from all other available sources. They are at various points in the division and are valuable for the information furnished as to the discharge at given times.

Miscellaneous gagings in the South Platte River Basin.

[Compiled from the seepage measurements made by the State engineer's office at Denver, Colo.]

Stream.	Locality.	1889.		1890.		1891.		1892.		1893.		1894.	
		Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.
			Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
South Platte River	Platte Canyon		131		209		204		153		133		186
Plum Creek	Mouth		3		2		3		15		6		6
South Platte River	Littleton		13		198		85		222		39		67
Bear Creek	Mouth		3		4		7		13		7		9
South Platte River	Denver		66		241		90		284		77		219
Clear Creek	Mouth		1		1		1		68		1		8
South Platte River	Brighton		8		127		74	Mar. 7 to Mar. 15	272		36		109
Do	Platteville		10		98		90		332		7		97
St. Vrain Creek	Mouth		18		21		29		71		36		62
Big Thompson Creek	do	Oct. 18 to Oct. 25	7	Oct. 14 to Oct. 24	24	Oct. 23 to Nov. 5	13		85	Oct. 30 to Nov. 10	11	Oct. 16 to Nov. 4	28
South Platte River	Evans		46		27		88		450		86		214
Cache la Poudre River	Mouth		15		38		61		146		64		74
South Platte River	Below Poudre		120		213		.....		.....		.....		312
Do	Orchard		.....		156		107		.....		105		.....
Do	Fort Morgan		.....		25		.....		834		.....		.....
Do	Snyder		.....		13		187	.....	.....		51		142
Do	Merino		8		8		97	.....	.....		5		32
Do	Sterling		6		12		67	.....	.....		13		21
Do	Crook		0		4		40	.....	.....	.....			36
Do	Julesburg		0		.....		43	.....	.....	.....			2
Cache la Poudre	Canyon	Oct. 14	69	Oct. 16	81	Oct. —	98	Mar. —	65	Nov. —	52	Mar. —	99
Do	Below Larimer and Weld canal.	Oct. 15	33	do	77	do	54	do	.....	do	69	do	49
Do	Below Cache la Poudre canal.	Oct. 16	2	Oct. 17	2	do	56	do	.....	do	.....	do	.....
Do	Below Ogilvie ditch.	Oct. 17	3	Oct. 18	.....	do	.....	do	141	do	98	do	57
Do	Near mouth	do	10	do	33	do	61	do	176	do	61	do	77

Miscellaneous gagings in the South Platte River Basin—Continued.

Stream.	Locality.	1895.		1896.		1897.		1898.		1899.		1900.	
		Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.
			Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
South Platte River	Platte Canyon	Nov. 7	237	Nov. 6	153	Nov. 19	235	Oct. 27	228	Oct. 23	154	Oct. 19	98
Plum Creek	Mouth	Nov. 8	11	Nov. 7	6	Nov. 20	43	Oct. 28	15	Oct. 24	4	Oct. 20	3
South Platte River	Littleton	...do	294	...do	43	...do	259	Oct. 29	158	...do	60	...do	89
Bear Creek	Mouth	...do	24	...do	8	...do	48	...do	14	Oct. 26	13	...do	11
South Platte River	Denver	Nov. 9	430	Nov. 9	100	...do	878	...do	234	Oct. 27	89	Oct. 22	161
Clear Creek	Mouth	Nov. 11	54	...do	66	Nov. 22	52	Oct. 31	1	...do	0	...do	1
South Platte River	Brighton	Nov. 12	373	Nov. 10	132	Nov. 23	360	Nov. 1	62	Oct. 28	81	Oct. 23	82
Do	Platteville	Nov. 13	480	Nov. 11	173	Nov. 24	445	Nov. 2	65	Oct. 30	141	Oct. 24	44
St. Vrain Creek	Mouth	...do	82	Nov. 12	52	Nov. 25	77	Nov. 3	39	...do	95	...do	53
Big Thompson Creek	...do	...do	41	...do	35			...do	16	Oct. 31	39	...do	17
South Platte River	Evans	Nov. 14	648	...do	294			...do	225	Nov. 1	335	...do	193
Cache la Poudre River	Mouth	Oct. 21	123	Nov. 13	85			Nov. 4	74	...do	151	Oct. 25	85
South Platte River	Below Poudre	...do	827	...do	360			...do	302	...do	575	...do	299
Do	Orchard	Oct. 24	941	Oct. 22	940			Nov. 17	491	Nov. 3	614	Oct. 27	324
Do	Fort Morgan	Oct. 26	745	Oct. 24	41			Nov. 18	555	Nov. 4	703	...do	14
Do	Snyder	...do	686	...do	21			Nov. 19	533	Nov. 5	741	Oct. 29	26
Do	Merino	Oct. 28	692	Oct. 26	13					Nov. 7	553	Oct. 30	18
Do	Sterling	Oct. 29	672	...do	30					Nov. 8	581	Oct. 31	30
Do	Crook	Oct. 30	626	Oct. 28	31					Nov. 9	582	Nov. 1	51
Do	Julesburg	Oct. 31	586							Nov. 12	487	Nov. 2	76
Cache la Poudre	Canyon	Oct. 9	66	Nov. —								Sept. 4	118
Do	Below Larimer and Weld canal.	Oct. 10	1									Sept. 30	15
Do	Below Cache la Poudre canal.	Oct. 14	34	Nov. 13	10							Sept. 5	10
Do	Below Ogilvie ditch.	Oct. 15	71	Nov. 14	49								
Do	Near mouth	...do	117	...do	78							Sept. 7	45

a Measurements stopped by storms.

SEEPAGE MEASUREMENTS.

The subjoined tables, taken from the records of the state engineer's office of Colorado, illustrates the extraordinary return from seepage along the South Platte and its tributaries. Measurements have been made annually for a number of years, whenever circumstances would permit, by the state engineer's office and the agricultural college at Fort Collins, Colo., working in cooperation, from the year 1889, inclusive. As may be seen from the tables, the return from seepage increases irregularly from year to year, being naturally considerably less during a very dry year than during a wet year. The year 1896, for example, was very dry, and the returns were much less than they would have been normally. The year 1898 was again dry, and the return was again small.[a]

[a] For more detailed information upon this subject see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 559 to 573; Sixth, pp. 51 to 65; Seventh, 176 to 195; Eighth, 381 to 404; Ninth, 305 to 317; Tenth, 208 to 236. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 133.

Increase in volume of the South Platte River from the canyon to points measured, due to the return of waste or seepage waters.

Places where measurements were taken.	Oct., 1889.	Oct., 1890.	Oct., 1891.	Mar., 1892.	Oct., 1893.	Oct., 1894.	Oct. and Nov., 1895.	Oct. and Nov., 1896.	Nov. 19 to 25, 1897.	Oct. and Nov., 1898.	1899.	1900.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
River below Head City ditch	.....	.....	27.57	25.32	18.41	49.23	20.12	10.18	.....	1.21	72.93	33.96
River at Littleton	49.91	11.73	80.18	69.95	41.91	74.82	75.44	24.94	.....	27.65	133.89	74.13
River at Denver	50.91	55.61	96.38	129.56	83.18	193.74	193.24	58.89	62.32	89.28	150.29	90.35
River at Fulton ditch	.....	94.41	138.85	141.51	127.03	228.06	174.05	74.61	138.24	112.78	196.90	86.96
River at Brighton	77.02	98.91	175.19	116.17	152.91	278.04	207.13	126.81	160.79	138.94	274.38	160.62
River at Evans's No. 2 ditch	.....	.....	.....	.....	208.74	314.72	276.76	171.24	237.29	227.92	324.33	.....
River at Elwood & Wheeler ditch	119.10	172.35	218.69	136.33	.....	.....	.....	.....	.....	.....	.....	.....
River at Platteville	133.38	.....	226.93	180.54	218.82	343.05	341.57	219.05	291.54	251.29	363.05	216.70
River above St. Vrain Creek	.....	155.80	233.32	.....	.....	.....	.....	.....	.....	.....	.....	.....
River at Union ditch	.....	.....	.....	.....	252.81	398.70	362.28	228.78	.....	328.44	410.74	257.76
River at Evans	197.00	176.91	299.21	192.86	279.93	450.51	385.85	256.64	.....	362.26	474.59	330.80
River at Cache la Poudre	.....	215.20	326.13	216.17	318.20	474.86	443.05	276.88	.....	466.31	.....	353.43
River at Hoover ditch	277.10	351.66	392.66	285.25	.....	549.75	557.58	309.71	.....	482.47	564.07	.....
River at Hardin ditch	.....	.....	.....	.....	387.23	498.70	522.31	325.33	.....	497.38	.....	409.08
River at Putnam ditch	.....	333.60	418.80	330.61	365.78	549.12	565.26	344.63	.....	522.39	624.97	412.94
River at Orchard	.....	.....	.....	.....	.....	.....	671.86	344.99	.....	553.41	628.22	439.54
River at Fort Morgan canal	305.92	360.58	434.05	360.09	414.33	.....	.....	.....	.....	.....	.....	.....
River at Shaffers Ford	.....	.....	.....	.....	.....	617.43	717.78	375.38	.....	568.32	715.57	469.07
River above Bijou Creek	.....	.....	.....	.....	.....	676.88	800.92	392.85	.....	594.40	.....	.....
River at Platte and Beaver canal	307.03	367.09	472.14	431.74	464.04	631.45	.....	.....	.....	.....	.....	.....
River at Fort Morgan	.....	.....	.....	.....	.....	.....	799.37	425.24	.....	617.01	722.71	.....
River at Snyder	.....	384.18	470.60	.....	479.67	707.64	814.19	478.03	.....	654.14	795.34	596.50
River below Big Beaver Creek	.....	.....	.....	.....	.....	714.90	879.57	499.41	.....	.....	.....	.....
River at Merino	385.58	405.71	550.32	.....	514.39	766.31	959.45	544.24	.....	.....	829.21	682.54
River at Sterling	418.33	435.16	583.69	.....	548.15	.....	1,006.25	576.84	.....	.....	962.94	744.07
River 2 miles above Iliff	422.77	449.21	611.76	.....	572.99	.....	1,023.24	598.20	.....	.....	1,009.13	749.26
River 2 miles above Crook	.....	.....	598.69	.....	.....	810.11	.....	.....	.....	.....	.....	.....
River at Crook	.....	.....	.....	.....	.....	.....	975.19	629.28	.....	.....	1,078.51	772.90
River at Pole Creek	.....	.....	.....	.....	.....	.....	989.98	.....	.....	.....	.....	.....
River at State line	.....	.....	602.00	.....	.....	775.94	942.30	.....	.....	.....	1,119.74	800.19

KANSAS RIVER BASIN.

A considerable portion of eastern Colorado is drained by the head-waters of Kansas River, the principal tributaries being branches of Republican and of Smoky Hill rivers. These streams, unlike the other streams of Colorado, do not originate in the mountains; they derive their water supply directly from the run-off and underground flow of the plains. The measurements of the General Land Office show that there are about 9,459 square miles in Colorado belonging to this drainage basin. This territory, although not belonging physically either to the South Platte division or to the Arkansas division, is divided in accordance with the Colorado laws between the two, the lands drained by the North and Middle forks of the Republican and their tributaries constituting district No. 65 and being apportioned to irrigation division No. I, the South Platte division; while the lands drained by the South Fork of the Republican and the Smoky Hill rivers and their tributaries constitute district No. 49 and are allotted to irrigation division No. II, the Arkansas division. The water supply of all these streams is small, but a number of ditches have been constructed and irrigation is carried on so far as it is possible. Only a few gagings have been made upon these streams in Colorado, and these are given below in the list of miscellaneous measurements. Stations have been maintained in Nebraska, however, and some of the records of those nearest to the Colorado line are given, as found in the records of the U. S. Geological Survey.[a]

FRENCHMAN RIVER AT WAUNETA AND PALISADE, NEBR.

The station at Wauneta was located in 1895. It is the highest station upon the Frenchman, being about 25 miles east of the line between Colorado and Nebraska. The channel has not proved favorable to accurate results and the station was therefore discontinued in 1896.

The station at Palisade was located October 14, 1894, at a point about three-fourths of a mile above the railroad station at Palisade, or about 16 miles below the gaging station at Wauneta. The results were unsatisfactory here, also, and the station was discontinued in 1896.

The results have considerable importance in connection with any investigation of the Colorado water supply, as the greatest source of supply for the streams of this section is the underground flow of eastern Colorado.

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[a] For more detailed information concerning this drainage basin see publications U. S. Geological Survey: Sixteenth Annual Report, Part II, p. 547; Eighteenth, Part IV, p. 194; Nineteenth, Part IV, p. 337; Twentieth, Part IV, p. 304; Bulletins No. 131, p. 32; No. 140, p. 123. For earlier history and description see Vol. XVII, Tenth Census, p. 56; also Eighth Biennial Report of State Engineer of Colorado, p. 21; and Artesian and Underflow Investigations, Ex. Doc. No. 222, Fifty-first Congress, first session, and Ex. Doc. 53, Parts 1 and 2, Fifty-first Congress, second session.

Estimated monthly discharge of Frenchman River at Palisade, Nebr.

[Drainage area, 1,032 square miles.]

Month.	Mean.	Total.	Run-off.	
			Per square mile.	Depth.
1895.	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*
April	137	8,152	0.13	0.14
May	129	7,932	.13	.15
June	117	6,962	.11	.12
July	99	6,087	.10	.12
August	78	4,796	.08	.09
September	74	4,403	.07	.08
	106	38,430	.10	.70
1896.				
May	114	7,010	.11	.13
June	104	6,188	.10	.11
July	94	5,780	.09	.10
August	76	4,673	.07	.08
September	82	4,879	.08	.09
October	83	5,103	.08	.09
	92	33,488	.09	.60

NORTH AND SOUTH FORKS OF REPUBLICAN RIVER AT BENKELMAN, NEBR.

These stations are fully described in the reports to which reference has already been made in connection with the Kansas Basin. They are located upon the two forks of Republican River, near Benkelman, Nebr., about 20 miles east of the Colorado line.

The channel is in each case sandy and shifting, and frequent changes in the rating tables are necessary. Both stations were established in November, 1894, and were maintained only until the fall of 1895, when they were discontinued owing to the unsatisfactory nature of the results. A few gagings have since been made, which are included in the list of miscellaneous measurements below, page 69.

Estimated monthly discharge of North Fork Republican River at Benkelman, Nebr.

[Altitude, 2,968 feet; drainage area, about 4,900 square miles.]

Month.	Mean.	Total.
1895.	*Second-feet.*	*Acre-feet.*
March	78	4,796
April	59	3,511
May	25	1,537
June	155	9,223
July	124	7,379
August	34	2,091
September	Dry.	0

MISCELLANEOUS GAGINGS IN THE KANSAS RIVER BASIN.

In the following table are given the results of gagings of streams in the Kansas River Basin made during several years by hydrographers acting under the direction of the United States Geological Survey.

Miscellaneous gagings in the Kansas River Basin.

Stream.	Locality.	Date.	Hydrographer.	Discharge.
				Sec.-ft.
Chief Creek	5 miles below Robb, Colo.	Mar. 23, 1891	L. R. Hope	20
North Fork Republican River.	6 miles below Robb, Colo.	do	do	21
Do	3 miles below Wray, Colo.	Apr. 24, 1891	do	51
Do	At State line	do	do	70
South Fork Republican River.	2½ miles west of State line.	Apr. 26, 1891	do	78
Arikaree Creek	3 miles west of State line.	Apr. 27, 1891	do	14
Frenchman River	Wauneta, Nebr	Aug. 9, 1895	O. V. P. Stout	61
Do	do	Sept. 10, 1895	do	56
Do	do	May 15, 1896	C. E. Crownover	85
Do	do	June 18, 1886	O. V. P. Stout	48
Do	do	July 14, 1896	E. G. Youngfelt	91
Do	do	Aug. 12, 1896	O. V. P. Stout	46
Do	do	Sept. 16, 1896	E. G. Youngfelt	85
Do	do	Oct. 17, 1896	C. E. Crownover	63
Do	Palisade, Nebr	Dec. 8, 1894	O. V. P. Stout	116
Do	do	Mar. 22, 1895	do	100
Do	do	June 5, 1895	do	154
Do	do	July 4, 1895	do	74
Do	do	Aug. 9, 1895	do	68
Do	do	Aug. 10, 1895	do	72
Do	do	May 15, 1896	C. E. Crownover	103
Do	do	June 18, 1896	O. V. P. Stout	51
Do	do	July 15, 1896	E. G. Youngfelt	93
Do	do	Aug. 13, 1896	O. V. P. Stout	64
Do	do	Sept. 16, 1896	E. G. Youngfelt	85
Do	do	Oct. 17, 1896	C. E. Crownover	83
North Fork Republican River.	Benkelman, Nebr	Dec. 9, 1894	O. V. P. Stout	75
Do	do	Mar. 23, 1895	do	72
Do	do	June 4, 1895	do	141
Do	do	June 24, 1895	do	36
Do	do	Aug. 7, 1895	do	64
Do	7 miles west of Benkelman, Nebr	June 16, 1896	do	88
Do	Benkelman, Nebr	do	do	29
Do	do	Aug. 25, 1896	E. G. Youngfelt	0

Miscellaneous gagings in the Kansas River Basin—Continued.

Stream.	Locality.	Date.	Hydrographer.	Discharge.
				Sec.-ft.
South Fork Republican River.	Benkelman, Nebr.	Dec. 9, 1894	O. V. P. Stout	1
Do	do	Mar. 23, 1895	do	41
Do	do	June 4, 1895	do	348
Do	do	June 24, 1895	do	75
Do	do	July 3, 1895	do	278
Do	do	Aug. 7, 1895	do	22
Do	do	June 16, 1895	E. G. Youngfelt	3
Do	do	Aug. 18, 1900	O. V. P. Stout	3
North Fork Republican River.	do	do	do	42
Frenchman River	Wauneta, Nebr	July 27, 1900	A. B. McCoskey	74
Do	Palisade, Nebr	do	do	91

ARKANSAS RIVER DIVISION.

DRAINAGE.

The drainage basin of Arkansas River has been so fully described in other reports[a] that but a brief description of its physical character is necessary at this time. The river rises a little west of the center of the State, near Leadville, and flows southerly and westerly until it passes into Kansas, a short distance above Coolidge. Until Canyon is reached the country passed through is in general rather mountainous and comparatively little irrigation is practiced, the water being used mainly for power, for domestic supply, and for placer mining, and here and there only for irrigation in a small way. At Canyon, however, the valley becomes broader, and when the river reaches Pueblo it enters the broad plains of eastern Colorado, upon which the irrigation practiced is limited only by the amount of water available.

The territory drained by the Arkansas and its tributaries forms irrigation division No. II,[b] which is subdivided into a number of water districts. These are district No. 11,[c] at the head of the Arkansas, in which there is but little irrigation and the water is used principally for storage, placer mining, and for the development of power; district

[a] See Hayden's reports, and publications of the U. S. Geological Survey as follows: Tenth Annual Report, Part II, pp. 69 and 86; Eleventh, Part II, pp. 45 and 300; Thirteenth, Part III, p. 362; Seventeenth, Part II, p. 557; Eighteenth, Part IV, p. 223; Nineteenth, Part IV, p. 351; Twentieth, Part IV, p. 323; Twenty-first, Part IV, p. 229; Bulletin No. 131, p. 34; No. 140, p. 153; Water-Supply and Irrigation Paper No. 37, p. 225; No. 59, p. 319. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97.

[b] Fourth Biennial Report Colorado State Engineer, Part I, p. 46; for map see Fourth Biennial Report, Part II, Plate I; Seventh Biennial Report, the same. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97.

[c] For map see Pl. I in Part II of Fourth and Seventh and Pl. II in Part II of Fifth Biennial Report of State Engineers.

No. 12,[a] the Canyon district, where irrigation is extensively practiced, both upon the main stream and upon its tributaries; district No. 14,[a] the Pueblo district, where the larger canals begin to divert the water of the main stream; district No. 17,[a] the Rockyford district, in which irrigation is very extensively practiced, the largest canals in the State having their headgates in this district, and district No. 67,[b] where the waters are entirely used for irrigation, enormous canals and reservoirs diverting the total flow during the greater portion of the year. The districts comprising the territories drained by the more important of the tributaries are as follows:

District No. 10,[c] comprising the drainage basin of Fontaine Qui Bouille; No. 13,[d] comprising the drainage basin of Grape Creek; No. 15,[e] of the St. Charles; No. 16,[f] of the Huerfano and Cucharas; No. 18,[b] the Apishapa; No. 19,[b] the Purgatory, and No. 66, in which a little irrigation is practiced upon the tributaries of the Dry Cimarron.

District No. 49,[g] in which are the headwaters of the South Fork of the Republican, can hardly be classed with any of the divisions, as it is not of the drainage basin either of the South Platte or of the Arkansas, but lies between the two, and comprises, with No. 65, the headwaters of the Kansas. Of the various tributaries of the Arkansas, those which enter the stream above Pueblo may be classed as mountain streams, while those entering below that city have more of the nature of streams of the plains, although several of them, as the Huerfano, the Apishapa, and the Purgatory, head in the mountains.[h] As is the case in the South Platte drainage, the mountain streams are perennial in nature, although there is a very high stage in the spring and early summer and a very low stage in the fall and winter. The plains streams are nearly always dry, except after storms and for comparatively short distances near their heads, where the water is generally used for irrigation. Although by far the greater portion of the water of the Arkansas is used, there are still opportunities for storage, especially along some of the plains streams. If water is to be stored, however, such canals must be constructed as will safely divert great quantities of water for short durations of time, and convey them to large reservoirs in the plains, where there are many sinks or depressions available. A number of reservoirs have been segregated

[a] For map see Pl. I in Part II of Fourth and Seventh and Pl. II in Part II of Fifth Biennial Reports of State Engineers.

[b] For map see Pl. I in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[c] For map see Pls. I and IX of Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[d] For map see Pl, I in Part II of Fourth and Seventh Biennial Reports of State Engineers.

[e] For map see Pls. I and XI in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[f] For map see Pls. I and XII in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[g] See page 69.

[h] For thorough investigation of the plains region see Seventeenth Annual Report U. S. Geological Survey, Part II, p. 557.

in this basin by the General Government, but no careful surveys have been made of any of them, excepting a few at the head of the Arkansas.[a] The principal reservoirs of this division now in use are Twin Lakes[b] reservoir (see figs. 2, 3, and 4), which is being used by the Twin Lakes Land and Water Company, and the reservoirs of the Great Plains Water Company, the latter being located about 12 miles north of Lamar in great natural depressions[c] (see fig. 6).

The agriculture of the Arkansas River, as well as of the South Platte, is exceedingly varied, on the upper portions only hay and grain being cultivated, while throughout its middle and lower courses fruit is extensively raised, and lower down melons, sugar beets, and alfalfa are among the staples. Horse, cattle, and sheep raising are extensively practiced throughout the division.

STREAM MEASUREMENTS.

Stations have been maintained upon the main stream and its tributaries in the division for longer or shorter periods of time at Twin Lakes, Granite, Salida, Canyon, Pueblo, Nepesta, Manzanola, Rocky-

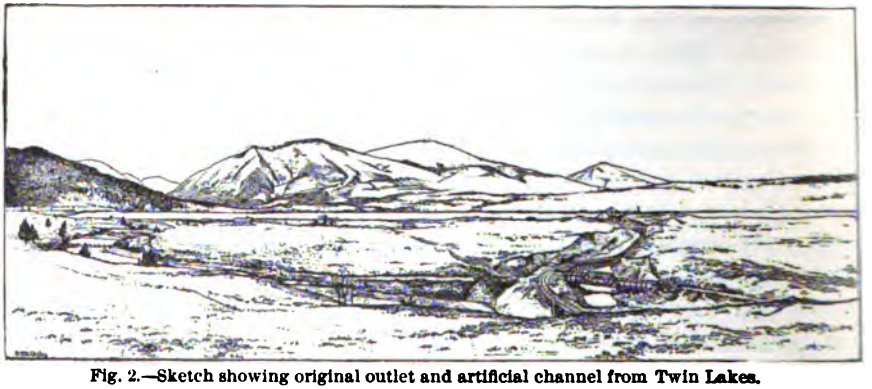

Fig. 2.—Sketch showing original outlet and artificial channel from Twin Lakes.

ford, La Junta, Las Animas, Prowers, Lamar, Granada, upon the main stream, and at Trinidad, J. J. ranch, and Las Animas on the Purgatory. Of the stations named those at Manzanola, La Junta, Las Animas, and Granada are unimportant, so far as this compilation is concerned, as the results obtained have not been of sufficient value to warrant the deduction of any conclusions from them. Those at J. J. ranch and Las Animas on the Purgatory are also omitted for the same reason. The measurements made at these points, however, will be found in the list of miscellaneous measurements (p. 99).

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[a] See Annual Reports U. S. Geological Survey: Tenth, Part II, p. 58; Eleventh, Part II, p. 15[illegible]; Twelfth, Part II, p. 55; Thirteenth, Part III, pp. 362-370; Twentieth, Part IV, p. 31.

[b] See Annual Reports U. S. Geological Survey: Tenth, Part II, p. 95; Eleventh, Part II, p. 15[illegible]; Thirteenth, Part III, pp. 365 and 460; Nineteenth, Part IV, p. 352; Twentieth, Part IV, p. 3[illegible]3, and Twenty-first, Part IV, p. 238.

[c] For descriptions see Reports last cited; also Twenty-first Annual Report, Part IV, p. 240.

A. QUEEN RESERVOIR DAM, NORTH OF LAMAR.

B. KICKING BIRD CANAL, NORTH OF LAMAR.

LAKE CREEK AT TWIN LAKES.

Lake Creek enters the Arkansas a short distance above the town of Granite. It is not a large stream, but it is of considerable importance owing to the fact that within its basin lie the Twin Lakes, used as reservoirs by the Twin Lakes Land and Water Company. No regular measurements have been maintained upon this stream, those that are given being derived from various sources and made in various places. The present stations are two in number, one between the two lakes, known as

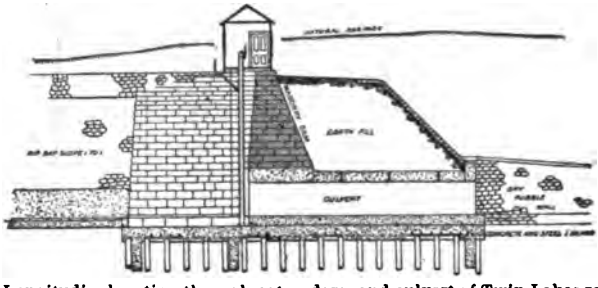


Fig. 3.—Longitudinal section through gates, dam, and culvert of Twin Lakes reservoir.

the Interlaken Station, and one below the lower lake, known as the Lower Twin Lakes Station. Measurements may be made at either station at low water by wading, but at high water advantage may be taken of bridges constructed across the stream. The channel at the Interlaken station is good, but this station must necessarily be abandoned as soon as the water is raised above what was the highwater mark before the construction of the dam described in the Twenty-first Annual Report, Part IV. At the

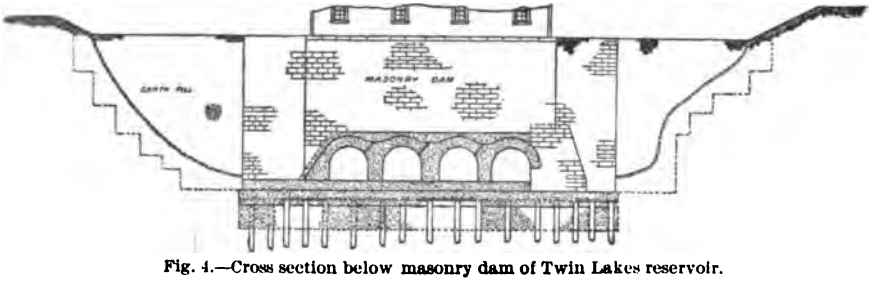
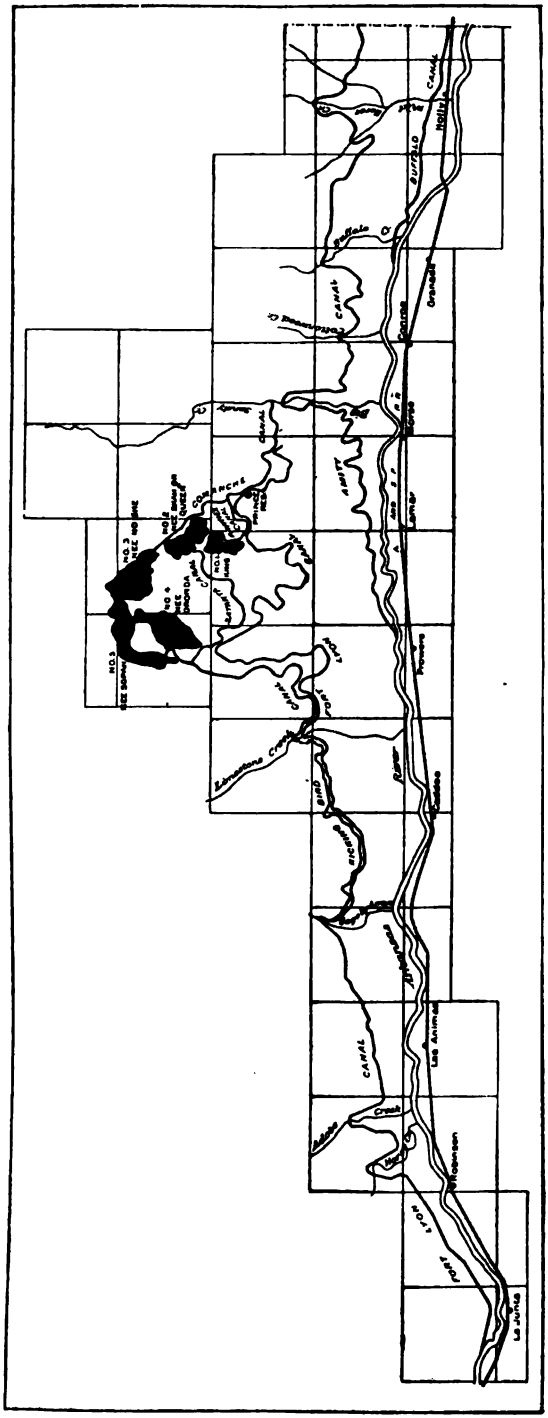


Fig. 4.—Cross section below masonry dam of Twin Lakes reservoir.

lower station the channel is rocky, but fairly permanent in its nature, and the banks are high and not liable to overflow.

The importance of the stations lies in the facts that the data obtained will furnish information concerning available power and will be of especial value in determining the amount of water to which the Twin Lakes Land and Water Company is entitled at its head gates. The waters of this stream are also largely used in placer mining.[a]

[a] For more detailed data concerning these stations, see Tenth Biennial Report of the State Engineers of Colorado, p. 293, and publications of the U. S. Geological Survey, as follows: Eleventh Annual Report, Part II, pp. 47 and 96; Twelfth, Part II, Pl. LXVI, opposite p. 240; Twenty-first, Part IV p. 238; Water-Supply and Irrigation Papers No. 37, p. 256; No. 39, p. 449; and No. 50, p. 320.


Buffalo Canal
Buffalo Creek
Buffalo
Canal
Greeley
Lower
Canal
Lower
Canal
Lower
Canal

Estimated monthly discharge of Lake Creek at Twin Lakes.

[Altitude, 9,012 feet; drainage area below both lakes, 109 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
June 21 to 30			847	50,519	7.79	8.69
July	667	370	454	27,915	4.17	4.81
August	588	230	381	23,427	3.50	4.04
September 1 to 11			194	11,543	1.78	1.99
July 22 to 31			206	4,086	1.89	.79
August	182	40	119	7,317	1.09	1.26
September 1 to 8			35	555	.32	.10

Discharge measurements made on Lake Creek at Twin Lakes.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1899.		*Feet.*	*Sec.-ft.*	
July 17	A. L. Fellows	2.80	273	At old station No. 1. (Station in channel above upper lake.)
Oct. 12	do	1.90	27	
1899.				
June 21	O. O. McReynolds	3.60	1,007	At old station No. 2. (Station at bridge over channel between lakes.)
July 17	A. L. Fellows	1.90	374	
Oct. 12	do	1.40	42	
1900.				
July 9	A. L. Fellows	1.70	203	
July 16	O. O. McReynolds	1.00	146	
1900.				
July 10	A. L. Fellows	.85	248	Interlaken Station. (Station at head of channel between lakes.)
July 18	do	.50	122	
Aug. 3	O. O. McReynolds	.25	52	
Sept. 4	C. W. Beach	.15	25	
1899.				
June 21	O. O. McReynolds	3.80	1,208	Old station No. 3. (Station at head of channel discharging from lower lake.)
June 27	do	3.20	696	
July 17	A. L. Fellows	2.55	391	
July 24	O. O. McReynolds	2.50	344	
Aug. 14	do	2.50	183	
Oct. 13	A. L. Fellows		22	
1900.				
July 10	A. L. Fellows	2.50	193	
July 16	O. O. McReynolds	2.40	245	Lower Twin Lakes Station. (Station below junction of old channel and new cut discharging from lake.)
July 18	A. L. Fellows	2.35	210	
July 18	do	2.50	260	
July 18	do	1.97	118	
Aug. 11	O. O. McReynolds	2.13	156	
Sept. 4	C. W. Beach	1.30	25	

ARKANSAS RIVER AT GRANITE

This station was located at the wagon bridge across the Arkansas at Granite, measurements being made from this bridge. The results are not of great value, owing to the extremely changeable nature of the channel, which lies in beds of bowlders and gravel and shifts constantly. For that reason measurements and records have not been kept up closely. The present condition of the channel seems to be somewhat more stable, however, and the station may be reopened. It is important from the fact that the discharge of the entire upper portion of the Arkansas, which is of the most value for the development of power and for placer mining, may be learned from the data obtained at this point.[a]

Estimated monthly discharge of Arkansas River at Granite.

[Altitude, 8,930 feet; drainage area, 425 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per sqare mile.	Depth in inches.
1897.						
May	2,058	268	1,109	68,190	2.61	3.01
June	2,162	923	1,459	86,817	3.43	3.83
July	1,096	444	719	44,209	1.69	1.95
August	546	176	350	21,520	.82	.94
September	350	114	169	10,057	.40	.45
October	114	114	114	7,009	.27	.31
November	.....	.....	[b] 115	6,843	.27	.30
December	.....	.....	[b] 115	7,071	.27	.31
1898.						
August	151	75	113	6,948	.27	.31
September	93	8	45	2,678	.11	.12

[a] For more detailed information concerning this station see Biennial Reports of the State Engineer of Colorado: Eighth, p. 484; Ninth, p. 359; Tenth, p. 296. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, pp. 47 and 96; Nineteenth, Part IV, p. 358; Twentieth, Part IV, p. 330; Water-Supply and Irrigation Papers, No. 16, p. 117; No. 28, pp. 110, 116, and 117; No. 37, p. 257; No. 39, p. 449. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 104.

[b] Approximate.

Discharge measurements made on Arkansas River at Granite.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
July 3	A. P. Davis	0.50	1,065
Sept. 26	do	3.10	215
1897.			
Apr. 17	C. C. Babb	3.20	120
May 8	F. Cogswell	4.20	940
May 18	do	4.90	1,236
June 29	do	4.60	1,151
July 27	do	3.75	415
Aug. 31	do	3.20	206
Sept. 27	do	3.10	203
Nov. 6	do	3.00	153
1898.			
July 30	A. L. Fellows	3.50	151
Aug. 26	do	3.40	112
Oct. 26	do	3.30	75
1899.			
May 25	do	5.00	1,476
July 15	do	2.80	1,178
Oct. 14	do	1.60	130
1900.			
July 9	do		570

ARKANSAS RIVER AT SALIDA.

This station is located at the footbridge near the railroad shops at Salida. It was established April 11, 1895, and has been maintained for a portion of each year since that time. The gage rod has been fastened to the north side of the footbridge, but considerable difficulty has been experienced owing to the fact that ice and logs constantly interfere with the rod, three new rods having been required in 1900. The banks are high and are not subject to overflow, but there are large bowlders in the stream which interfere with the accuracy of the results of measurements.

The importance of the maintenance of the station lies in the information furnished as to the time required for water to flow from Granite to Salida and again from Salida to Canyon, this question having a bearing upon the distribution of the use of the water turned out from Twin Lakes; and it is, moreover, valuable from the point of view that it is extremely probable that the entire discharge of the Arkansas at this point may eventually be used for power purposes in the Grand Canyon of the Arkansas.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 480; Ninth, p. 361; Tenth, p. 298. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 224; Nineteenth, Part IV, p. 355; Twentieth, Part IV, p. 331, Twenty-first, Part IV, p. 230. Bulletin No. 140, p. 155; Water-Supply and Irrigation Papers, No. 16, p. 118; No. 28, pp. 110 116, and 117; No. 37, p. 258; No. 39, p. 450: and No. 50, p. 322. Also report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 104.

Discharge of Arkansas River at Salida.

[Altitude, 7,085 feet; drainage area, 1,160 square miles.]

Month.	1895.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Run-off.[a]	
								Second-feet per square miles.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
March	.....	.....	.....	[b] 308	.....	[c] 308	18,938	0.27	0.31
April	[d] 1,117	.....	.....	398	155	557	33,143	.48	.54
May	1,545	1,646	.....	1,352	1,790	1,583	97,335	1.36	1.57
June	1,599	1,839	.....	2,639	2,083	2,040	121,388	1.76	1.96
July	1,159	985	.....	1,301	633	1,020	62,717	.88	1.01
August	860	518	280	497	320	495	30,436	.43	.49
September	537	397	199	281	291	341	20,291	.29	.32
October	402	289	223	.....	192	277	17,032	.24	.28
November	.....	.....	267	.....	.....	[c] 267	15,888	.23	.26
Mean	1,031	946	242	968	780	765	417,168	0.66	6.74
Acre-feet for period recorded	416,976	345,184	58,560	370,560	331,058	.....	.....	.....	.....

[a] The run-off for acre-feet given is for that part of each year covered by the observations (and estimates) given, and for a thirty-day month at the rate given as the mean for the whole period of each year covered, while the discharge is for average months and the total for an average nine months from March to November, inclusive, as calculated from the observations and estimates. Details may be found in the authorities cited.

[b] March 22 to 31, inclusive.

[c] One year only, but approximately correct.

[d] April 11 to 30, inclusive.

Maximum and minimum discharge and average run-off of Arkansas River at Salida for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Oct. 13	402	May 14	2,462	0.99	0.89
1897	Oct. 4	320	May 31	2,910	.91	.82
1898	Oct. 7	100	Aug. 2	428	.23	.21
1899	Sept. 28	240	June 20	3,900	.92	.83
1900	Apr. 14	65	June 1	3,633	.74	.67

Discharge measurements made on Arkansas River at Salida.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
Sept. 27	A. P. Davis	0.60	463
1896.			
May 26	T. Cogswell	3.10	[a] 2,023
June 24	do	1.40	638
Sept. 29	do	1.00	352
Oct. 27	do	.80	317
1897.			
Apr. 17	C. C. Babb	.69	219
Apr. 27	F. Cogswell	1.55	709
May 8	do	2.20	1,178
May 30	do	4.05	2,821
June 29	do	2.50	1,492
July 27	do	1.35	606
Aug. 31	do	.85	371
Sept. 27	do	1.00	405
Nov. 6	do	.90	378
1898.			
Apr. 27	A. L. Fellows	1.10	480
May 20	do	3.10	445
June 25	do	3.10	2,352
July 29	do	1.25	568
Aug. 26	do	.90	360
Oct. 26	do	.80	222

[a] Approximate; meter out of order.

Discharge measurements made on Arkansas River at Salida—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 26	A. L. Fellows	1.72	686
May 25	.....do	3.10	1,999
July 14	.....do	2.40	1,801
Nov. 18	.....do	.80	317
1900.			
Mar. 15	A. L. Fellows	.90	271
June 14	.....do	4.30	3,036
Aug. 8	.....do	1.08	443
Aug. 22	.....do	.87½	364

ARKANSAS RIVER AT CANYON.

This station is located near the Hot Springs Hotel, 1½ miles west of Canyon, and a short distance below the mouth of Grape Creek (see Pl. VII). It was established in the year 1889, and records have been kept up ever since that time, thus furnishing a most valuable table of discharge of the Arkansas River. The station is of particular importance as it is located at the mouth of the canyon and above practically all the irrigating ditches excepting the Canyon ditch and the South Canyon ditch, which draw their supplies at short distances above the station. Each of these carries from a very few feet up to 60 cubic feet per second, according to need during the irrigation season.

The table does not include the amounts carried by the canals, and their flow should be added to the discharge of the river at the station in order to get the total run-off at the mouth of the canyon. The channel is fairly constant, changing but little during the entire time that the station has been maintained. The banks are high and not subject to overflow.[a]

[a] For more detailed data concerning this station, see Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 62, and Part II, Pl. XVI; Fifth, Part I, pp. 21 and 38, and Part II, Pl. X; Sixth, pp. 19 and 24; Seventh, pp. 163 and 164; Eighth, p. 474; Ninth, p. 363; Tenth, p. 300. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, p. 97; Twelfth, Part II, pp. 240 and 349; Thirteenth, Part III, pp. 19 and 363; Fourteenth, Part II, p. 106; Eighteenth, Part IV, p. 225; Nineteenth, Part IV, p. 356; Twentieth, Part IV, p. 331; Twenty-first, Part IV, p. 231; Bulletins, No. 131, p. 35; No. 140, p. 156; Water-Supply and Irrigation Papers, No. 11, p. 60; No. 16, p. 119; No. 28, pp. 110, 116, and 117; No. 37, p. 258; No. 39, p. 450; No. 50, p. 323. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 112.

A. ARKANSAS RIVER AT CANYON.

B. DIVERTING DAM ON ARKANSAS RIVER AT CANYON.

Discharge of Arkansas River at Canyon.

[Altitude, 5,363 feet; drainage area, 3,060 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off.[a] Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	[b] 400	[b] 300	310	431	496	505	445	344	454	[b] 380	[b] 270	316	345	384	23,611	0.12	0.14
February	[b] 500	[b] 300	363	474	493	533	420	361	438	[b] 380	[b] 350	328	353	407	22,604	.13	.14
March	[b] 600	[b] 300	320	586	524	555	505	471	472	[b] 380	338	584	439	467	28,715	.15	.17
April	[b] 1,000	300	477	857	522	568	627	868	558	320	393	544	736	598	35,583	.20	.22
May	1,440	600	2,090	2,012	1,241	1,480	1,960	1,506	1,276	1,741	909	1,924	2,251	1,512	96,658	.51	.59
June	2,090	1,374	2,611	3,291	2,787	3,115	2,704	1,900	959	2,464	2,428	3,496	3,492	2,516	149,712	.82	.91
July	1,350	602	1,571	1,468	1,798	1,069	1,393	1,413	538	1,115	1,613	2,021	891	1,296	79,688	.42	.48
August	932	340	670	951	769	553	710	1,095	395	553	326	711	273	638	39,229	.21	.24
September	605	220	519	473	435	477	551	635	313	366	189	225	211	401	23,861	.13	.14
October	[b] 500	223	531	624	511	[b] 50	294	505	285	471	228	236	241	396	24,349	.11	.16
November	[b] 500	299	522	498	527	[b] 500	260	499	267	519	302	440	266	415	24,694	.13	.14
December	[b] 400	335	502	476	561	428	268	444	579	[b] 400	[b] 350	336	298	414	25,456	.14	.16
Mean[c]	860	433	874	1,012	889	857	845	837	544	757	640	930	816	792	574,160	0.26	3.49
Acre-feet[c]	632,105	313,153	634,453	733,588	645,320	620,477	612,584	607,507	393,624	549,322	464,559	673,279	590,452	.....	.....	.....	.....

[a] The run-off in acre-foot given is for each entire year, including estimated months; the discharge given is for average months, and the tables for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

[b] Approximate.

[c] For entire year.

Maximum and minimum discharge and average run-off of Arkansas River at Canyon for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. 28	420	June 19	2,760	3.80	[illegible]
1889	Oct. 12	190	Aug. 9	2,620	1.92	[illegible]
1890	Jan. 14	180	May 28	3,270	3.88	[illegible]
1891	Jan. 11	325	June 13	4,230	4.49	[illegible]
1892	Jan. 15	345	June 25	4,750	3.95	[illegible]
1893	Aug.	200	June	4,750	3.80	[illegible]
1894	Oct.	245	June	4,400	3.74	[illegible]
1895	Dec. 16	256	June 11	2,588	3.71	[illegible]
1896	Nov. 28	124	Aug. 30	2,876	2.41	[illegible]
1897	Apr. 10	108	June 4	3,452	3.33	[illegible]
1898	Oct. 3	160	June 19	3,245	2.84	[illegible]
1899	Feb. 18	160	June 20	4,432	3.98	[illegible]
1900	Sept. 22	194	May 29	4,251	3.50	[illegible]

[a] The run-off given is for each entire year, including estimated months. Details may be found in the authorities cited.

Discharge measurements made on Arkansas River at Canyon.

Date.	Hydrographer.	Gage height.	Discharge.
1889.		*Feet.*	*Sec.-ft.*
July 26	Robert Robertson	2.25	[illegible]
July 26	do	3.00	[illegible]
1890.			
Apr. 1	Robert Robertson	1.62	[illegible]
Apr. 2	do	1.70	[illegible]
Apr. 3	do	1.88	[illegible]
Apr. 28	do	2.93	[illegible]
May 1	do	2.73	[illegible]
May 2	do	2.80	[illegible]
May 2	do	2.78	[illegible]
May 23	do	4.77	[illegible]
June 5	do	4.85	[illegible]
June 12	do	4.53	[illegible]
June 14	do	4.65	[illegible]
June 19	do	4.48	[illegible]
June 23	do	4.55	[illegible]
June 27	do	4.55	[illegible]
June 30	do	4.23	[illegible]
July 9	do	4.22	[illegible]
July 12	do	4.05	[illegible]
July 16	do	3.82	[illegible]

Discharge measurements made on Arkansas River at Canyon.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1891.		*Feet.*	*Sec.-ft.*
Apr. 13	T. M. Bannon	3.00	777
Dec. 4	do	1.85	328
1893.			
Sept. 22	F. H. Newell	2.45	291
1894.			
Apr. 15	F. H. Newell	4.20	2,395
May 18	do	3.80	1,940
June 18	do	4.80	2,387
Sept. 20	A. P. Davis	2.65	395
Oct. 15	do	2.40	319
1895.			
May 31	A. P. Davis	4.35	2,434
June 13	do	4.50	2,397
Oct. 4	do	2.70	585
1896.			
July 31	F. Cogswell	2.40	414
Aug. 30	do	2.00	203
Sept. 16	do	2.05	251
Oct. 31	do	2.20	289
Nov. 14	do	2.55	294
1897.			
Apr. 16	C. C. Babb	2.20	260
May 7	do	3.10	827
May 26	F. Cogswell	4.95	2,712
June 16	do	5.25	3,071
July 14	do	3.60	1,140
Aug. 11	do	3.05	744
Nov. 5	do	2.98	540
1898.			
May 21	A. L. Fellows	3.05	608
June 25	do	4.82	2,830
July 28	do	3.05	611
Oct. 27	do	2.60	316
1899.			
Apr. 27	A. L. Fellows	3.20	611
May 26	do	4.55	2,189
July 7	do	4.50	2,651
Aug. 18	do	2.90	553
Nov. 7	do	2.55	306
1900.			
Mar. 14	A. L. Fellows	2.85	408
June 14	do	5.50	3,235
July 20	do	2.85	570
Sept. 8	do	2.10	229
Sept. 12	R. W. Hawley	2.10	205

ARKANSAS RIVER AT PUEBLO.

The first records of the discharge of Arkansas River in the vicinity of Pueblo are for the months of May and June, 1885. From this time until August, 1889, records were kept more or less irregularly at a point near the mouth of the canyon, about 9 miles above the city of Pueblo. No other records were kept in this vicinity until September, 1894, when the station was relocated in the city of Pueblo. As only one large ditch, the Bessemer canal, takes water from the river in District No. 14, in which Pueblo is situated, the station answers admirably for assisting in the distribution of the waters of that district. Owing, however, to the changes in the channel, the construction of side walls, and the removal of a dam in the lower part of the city, it has been necessary to change the location of the rod from time to time. Up to the fall of 1898 the records of gage heights were taken from a rod situated at the north end of the Santa Fe avenue bridge; at that time, however, another rod was placed at the south end of the Main street bridge, and in March, 1900, another rod was placed at a point a short distance below the south end of the Union avenue bridge. This is the rod used at present. These changes in location have, however, no material bearing upon the actual discharge, as measurements have been taken frequently and these stations are practically one, being located in the same long stretch of clear, open channel, with no inflow, and having high retaining levees constructed by the city. (See Pl. VII, *B*.) The channel at present is probably the best in the State, although it fills to some extent at low water and scours out again at high stages. Measurements are usually made from the Main street bridge, but may be made by wading at low water.

In comparing the tables it should be borne in mind that the records for 1885 to 1889, inclusive, are for a point about 9 miles above the station for the later years, and that considerable water is taken out between the two points. Moreover, much less water was used on the higher reaches of the stream prior to 1889 than since that time, so that practically the two stations bear little relationship to each other. They are, however, given together for advantage in comparison. Measurements of the water level are kept up regularly by the office of the city engineer of Pueblo, and it is to this office that we are indebted for a large proportion of the records given in the tables.

This station is of particular importance, for, being near the head of one of the most important districts and also near the headquarters of the superintendent of the Arkansas division, it is of use in ascertaining the discharge of the river with reference to the proper distribution of the water amongst consumers. It is further important because the waters of the Arkansas are being used more and more for power, and

A. ARKANSAS RIVER BELOW MAIN STREET BRIDGE, PUEBLO.

B. ARKANSAS RIVER NEAR ROCKYFORD.

the surplus, whenever there is any, is being stored in large reservoirs, of which there are several important ones in the vicinity of Pueblo.[a]

Discharge of Arkansas River at canyon above Pueblo, 1885 to 1889, inclusive.

Month.	1885.	1886.	1887.	1889.	Average.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
May	1,069	3,046	.....	1,300	1,805
June	3,187	5,569	3,477	2,108	3,585
July	.....	1,724	3,352	766	1,947
August	.....	1,481	1,717	668	1,289
September	.....	1,372	1,129	.....	1,250

[a] For more detailed data concerning this station, see Biennial Reports of the State Engineers of Colorado: Third, pp. 168 to 174; Fourth, Part I, p. 62, and Part II, Pl. XVI; Eighth, p. 468; Ninth, p. 366; Tenth, p. 304. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, pp. 49 and 98; Eighteenth, Part IV, p. 227; Nineteenth, Part IV, p. 357; Twentieth, Part IV, p. 336; Twenty-first, Part IV, p. 232; Bulletin No. 140, p. 158; Water-Supply and Irrigation Papers, No. 11, p. 61; No. 16, p. 120; No. 28, pp. 111, 116, and 117, No. 37, p. 259; No. 39, p. 450; No. 50, p. 325. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

Estimated mean discharge of Arkansas River at Pueblo.

[Altitude, 4,690 feet; drainage area, 4,600 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	460	519	328	330	407	411	409	25,148	0.09	0.10
February	476	456	335	385	603	418	446	24,770	.10	.11
March	357	396	213	320	406	391	347	21,336	.08	.09
April	744	470	241	370	418	822	510	30,347	.11	.12
May	1,561	1,101	1,674	841	1,683	2,997	1,643	101,024	.36	.41
June	2,152	895	2,213	2,202	3,384	4,006	2,475	147,273	.54	.60
July	1,900	633	1,041	1,605	2,043	878	1,350	83,008	.29	.33
August	1,275	489	467	306	811	314	610	37,507	.13	.15
September	494	309	272	125	238	232	278	16,542	.07	.08
October	551	293	413	210	303	321	349	21,459	.08	.09
November	530	314	484	309	374	338	392	23,325	.09	.10
December	462	333	356	363	327	396	373	22,935	.09	.10
Mean	914	517	670	614	916	960	765	554,674	.17	2.28
Acre-feet, total	663,419	375,960	485,818	444,664	663,839	694,960	.....	.....	.....	.....

[a] The run-off given is for average months, and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Maximum and minimum discharge and average run-off of Arkansas River at Pueblo for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Dec. 26	256	June 13	2,588	2.72	0.20
1896	Aug. 10	203	Aug. 18	3,428	1.54	.11
1897	Mar. 13	146	June 2	3,750	1.98	.14
1898	Oct. 6	31	July 13	5,385	1.82	.13
1899	Sept. 13	150	June 20	4,891	2.73	.20
1900	Sept. 1	134	June 2	6,980	2.80	.21

[a] The run-off given is for each year entire, including estimated months; the discharge given is for average months, and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Discharge measurements made on Arkansas River at Pueblo.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Apr. 24	P. J. Preston	[a]	322
Sept. 19	A. P. Davis	0.35	378
Oct. 13	do	.39	370
1895.			
Feb 6	A. P. Davis	.40	411
May 20	do	1.65	1,435
June 3	do	[b]	2,261
June 4	do	[c]	1,973
June 4	do	[d]	2,022
June 11	do	2.80	2,758
Sept. 5	F. Cogswell	.70	570
1896.			
Mar. 22	F. Cogswell	.50	470
Apr. 8	do	1.30	1,016
May 27	do	2.00	1,682
June 5	do	1.65	1,403
July 10	do	.30	335
July 30	do	.50	510
Aug. 18	do	[e] .00	203
Aug. 19	do	.85	534
Aug. 19	do	10.00	16,500
Sept. 16	do	.30	294
Oct. 30	do	.35	320
Nov. 13	C. C. Babb	.31	298

[a] Measurement made at Main Street bridge.
[b] Measurement made at Swallows.
[c] Measurements made at Bridge No. 3, section 4.
[d] Measurements made at Bridge 155 B.
[e] Approximate estimate of flood at 12 m. night of August 18, 1896. A maximum velocity of 15 feet per second was obtained by means of floats.

Discharge measurements made on Arkansas River at Pueblo—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1897.		*Feet.*	*Sec.-ft.*
Apr. 16	C. C. Babb	0.20	216
May 6	F. Cogswell	1.00	799
May 21	.....do	2.00	1,856
June 18	.....do	2.55	2,219
July 16	.....do	1.15	981
Aug. 10	.....do	.95	805
Sept. 8	P. J. Preston	.10	184
Sept. 28	.....do	.45	394
Nov. 4	F. Cogswell	.75	601
1898.			
Apr. 5	P. J. Preston	.27	248
Apr. 29	A. L. Fellows	.06	513
May 5	C. W. Beach	.09	876
May 30	.....do	.10	1,144
June 3	.....do	1.40	1,639
June 9	A. L. Fellows	1.8	2,002
June 14	C. W. Beach	1.9	1,987
July 8	.....do	1.63	1,726
July 26	A. L. Fellows	[a] .85	816
July 28	C. W. Beach	[a] .81	743
Aug. 2	.....do	.45	405
Aug. 11	.....do	.50	468
Aug. 20	C. W. Beach, R. W. Hawley	.15	211
Aug. 30	A. L. Fellows	.00	134
Oct. 20	C. W. Beach	.20	290
Oct. 29	A. L. Fellows	.40	320
Nov. 3	C. W. Beach	.30	344
1899.			
Apr. 27	A. L. Fellows	.80	695
May 26	.....do	2.20	2,221
June 3	C. W. Beach	2.55	2,856
June 17	.....do	3.60	4,565
July 1	.....do	2.22	2,959
July 8	A. L. Fellows	1.61	2,098
Aug. 1	C. W. Beach	.72	1,199
Aug. 5	.....do	1.46	1,938
Aug. 14	A. L. Fellows	1.20	1,496
Sept. 10	.....do	.50	180
Sept. 18	C. W. Beach	.10	388
Oct. 6	.....do	.20	331
Nov. 7	A. L. Fellows	.05	411

[a] New gage rod at Main street.

Discharge measurements made on Arkansas River at Pueblo—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 3	A. L. Fellows	2.17	498
Mar. 16	.....do	2.05	435
Apr. 8	.....do	2.34	675
Apr. 12	C. W. Beach	2.15	608
May 21	.....do	5.70	5,072
June 13	A. L. Fellows	5.10	3,963
July 17	.....do	2.50	751
July 21	.....do	2.25	583
Sept. 3	R. W. Hawley	1.35	153
Sept. 5	C. W. Beach	1.43	191
Sept. 7	A. L. Fellows	1.40	174
Sept. 25	C. W. Beach	1.82	346

ARKANSAS RIVER AT NEPESTA.

This station is located at the wagon bridge a short distance above the railroad station of the Atchison, Topeka and Santa Fe Railroad at Nepesta, and is maintained by the Great Plains Water Company. It was established September 8, 1897, and records have been kept during each irrigation season since that time, only those for 1898, 1899, and 1900 being reliable, however. Two gage rods are necessary; one for use at high and the other at low water. Measurements are made from the wagon bridge. The channel is sandy and shifting and frequent changes are necessary in the rating table. The importance of the station is due to the fact that it is so conveniently located to the railroad station that representatives of the large irrigation canals upon the river may readily keep themselves informed as to the discharge and the use of the water of the stream.[a]

[a] For further information concerning this station, see Biennial Reports of the State Engineers of Colorado: Ninth, p. 370; Tenth, p. 308. Also publications U. S. Geological Survey: Nineteenth Annual Report, Part IV, p 358: Twentieth, Part IV, p. 337; Twenty-first, Part IV, p. 233; Bulletin No. 131, p. 37; Water-Supply and Irrigation Papers, No. 16, p. 121; No. 28, pp. 112, 116, and 117; No. 37, p. 260; No. 39, p. 450; No. 50, p. 326. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 124.

Estimated monthly discharge of Arkansas River at Nepesta.

[Altitude, 4,364 feet; drainage area, 9,130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
May	2,055	350	1,116	68,621	0.12	0.14
June	3,665	918	2,103	125,137	.23	.26
July	4,125	136	1,310	80,549	.14	.16
August	697	127	311	19,123	.03	.03
September	294	160	232	13,805	.03	.03
October	511	160	279	17,155	.03	.03
November	511	260	366	21,778	.04	.04
	.....	.....	817	346,168	.09	.69
1899.						
May	2,246	259	1,154	70,957	.13	.15
June	3,882	1,156	2,622	156,020	.29	.32
July	6,066	610	2,651	163,004	.29	.33
August	6,974	172	957	58,844	.10	.12
September	285	154	200	11,901	.02	.02
October	314	172	235	14,450	.03	.03
November	2,791	191	350	20,826	.04	.04
	.....	.....	1,167	495,002	.13	1.00
1900.						
May	9,600	4,246	5,876	361,301	.64	.74
June	7,782	4,064	5,498	327,154	.60	.67
July	3,700	427	1,699	104,467	.19	.22
August	1,519	172	422	25,948	.05	.06
September	427	172	262	15,590	.03	.03
October	610	314	435	26,747	.05	.06
November	792	259	514	30,585	.06	.07
	.....	.....	2,101	891,792	.23	1.85

Discharge measurements made on Arkansas River at Nepesta.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
May 31	F. H. Newell		[a]30,000
June 1	.....do		12,000
June 2	.....do		8,000
1897.			
Sept. 8	P. J. Preston	2.00	168
Sept. 30	.....do	2.34	281
1898.			
Apr. 27	P. J. Preston	2.55	360
May 6	C. W. Beach	3.05	746
May 10	.....do	4.25	1,998
June 6	.....do	3.43	1,060
July 28	.....do	3.25	573
Aug. 20	.....do	2.85	247
Nov. 6	.....do	2.93	212
1899.			
May 29	A. L. Fellows	4.60	1,810
June 7	C. W. Beach	4.63	1,636
Aug. 3	.....do	4.00	610
Aug. 25	.....do	3.10	215
Oct. 2	.....do	3.12	213
1900.			
Apr. 12	C. W. Beach	4.30	1,101
Sept. 8	R. W. Hawley	3.70	146

[a] Estimated.

ARKANSAS RIVER AT ROCKYFORD.

This station is located at the wagon bridge crossing the Arkansas River, at a point about 2 miles northeast of the town of Rockyford. It was established May 3, 1897, by Mr. S. W. Cressy, water commissioner of district No. 17, having his headquarters at Rockyford, for his convenience and information in distributing the waters of his district. Mr. Cressy maintained this station as long as he remained in charge of the office to April 7, 1900. The river is straight for a long distance above and below the bridge, but the channel is wide and the bed is sandy and very shifting, so that few measurements were made. Results must be considered as approximate.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Ninth, p. 374; Tenth, p. 310. Publications U. S. Geological Survey: Nineteenth Annual Reports, Part IV, p. 353; Twentieth, Part IV, p. 338; Twenty-first, Part IV, p. 234; Water-Supply and Irrigation Papers, No. 16, p. 122; No. 28, pp. 112, 116, and 117; No. 37, p. 261; No. 39, p. 450; No. 50, p. 327. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 124.

For description of Laguna Canal, in this district, see Twentieth Annual Report, Part IV, p. 339.

Estimated monthly discharge of Arkansas River at Rockyford.

[Altitude, 4,177 feet; drainage area, 11,440 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May 3 to 31	3,363	64	1,147	70,527	0.100	0.120
June	3,206	628	1,834	109,130	.160	.180
July	2,034	41	589	32,216	.052	.060
August	3,676	20	614	37,754	.054	.062
September	108	13	41	2,440	.004	.004
October	393	27	143	8,793	.013	.015
November	550	41	155	9,223	.014	.016
December[a]			50	3,074	.044	.051
1898.						
January			[a]75	[a]4,612	.007	.008
February 20 to 28	193	34	75	4,165	.01	.01
March	393	129	254	15,618	.02	.03
April	550	64	213	12,674	.02	.02
May	3,832	108	1,206	74,155	.12	.13
June	3,284	315	2,047	121,805	.18	.20
July	3,754	193	1,249	76,799	.11	.13
August	706	108	269	16,540	.02	.03
September	393	64	157	9,342	.01	.02
October	550	84	246	15,126	.02	.03
November	862	84	530	31,537	.05	.05
December	393	84	228	14,020	.02	.02
The year	3,832	34	546	396,393	.04	.68
1899.						
March 13 to 31	570	140	309	19,000	.027	.031
April	520	140	274	16,304	.024	.027
May	1,270	140	732	45,009	.064	.074
June	2,710	770	1,498	89,137	.131	.146
July	3,020	270	1,504	92,478	.131	.150
August	3,570	105	686	42,181	.060	.069
September	420	95	153	9,104	.013	.014
October	300	55	145	8,916	.013	.015
November	1,070	105	280	16,661	.024	.027
December 1 to 9	190	115	148	9,100	.013	.015
1900.						
January 16 to 31	470	190	319	19,061	.027	.031
February, 13 days	470	270	410	22,770	.036	.037
March	450	190	324	19,922	.028	.032
April 1 to 7	3,120	360	1,283	76,344	.112	.125

[a] Approximate.

Discharge measurements made on Arkansas River at Rockyford.

Date.	Hydrographer.	Gage height.	Discharge.
1897.		*Feet.*	*Sec.-feet.*
Sept. 29	P. J. Preston	0.37	140
1898.			
Apr. 17	P. J. Preston	.90	237
May 27	C. W. Beach	1.83	1,692
1899.			
May 30	A. L. Fellows	1.88	1,042
Oct. 16	do	.88	136

ARKANSAS RIVER AT PROWERS.

This station is located at the dam constructed across the Arkansas River at the headgate of the Colorado and Kansas canal, this point being selected in September, 1899, in the hope that the channel might prove permanent, but no records were kept until the spring of 1900. The rating curve obtained at this point from gagings made thus far gives excellent results within the limits of the measurements. There being no bridge at the station, measurements can be made only at the lower stages of the river. The station is of particular importance, owing to the fact that it is located near the head of irrigation district No. 67, and may therefore be used in the regulation of the use of the waters of the Arkansas in that district.[a]

Estimated monthly discharge of Arkansas River at Prowers.

[Altitude, 3,677 feet; drainage area, 19,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
April 15 to 30	7,140	1,060	2,940	174,942	0.155	0.173
May	5,860	2,660	3,398	208,935	.178	.238
June	4,900	742	2,617	155,722	.138	.154
July	1,700	2	161	9,990	.008	.009
August	445	0	45	2,767	.002	.002
September [b]	30	0	6	357	.000	.000
October [b]			6	369	.000	.000
November [b]	16	4	8	476	.000	.000
December	41	4	18	1,107	.001	.001

[a] For more detailed information regarding this station, see Tenth Biennial Report of the State Engineers of Colorado, p. 312; Water-Supply and Irrigation Papers, U. S. Geological Survey, No. 37, p. 263, and No. 50, p. 328; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

[b] Estimated.

Discharge measurements made on Arkansas River at Prowers.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Sept. 8	A. L. Fellows	0.20	16
1900.			
July 5	C. W. Beach	.60	304
July 19	A. L. Fellows	.38	113
July 28	C. W. Beach	.77½	546

ARKANSAS RIVER NEAR LAMAR.

The greater proportion of the records of this locality are those kept by the Amity Canal Company, their headgate being at a point 7 miles west of Lamar, on the north side of the river, the headgate keeper making a daily record of the discharge both in the river and the canal. (See Pl. IX.) There is a dam across the river at this point for the diversion of water into the Amity canal, but owing to the unevenness of its crest, to the fact that timbers and driftwood lodge upon it, and to other causes, the results are not entirely reliable. Few measurements have been made except in the canal. For a short time in the year 1899 estimates were made at the wagon bridge north of Lamar by the water commissioner of district No. 67. These are of interest as giving approximately an idea of the flow of the water for the time covered, and are therefore presented in a separate table.

The principal value of hydrographic data at this point is with reference to the storage of water in reservoirs, of which those of the Great Plains Water Company, described in the Twenty-first Annual Report, Part IV, p. 240, are located, 12 miles north of the town of Lamar.[a]

[a] For further information concerning this station, see Biennial Reports of the State Engineer of Colorado; Ninth, p. 379; Tenth, p. 314. Also publications United States Geological Survey: Eleventh Annual Report, Part II, pp. 49 and 51; Twentieth, Part IV, pp. 324 and 340; Water-Supply and Irrigation Papers, No. 28, p. 114; No. 37, p. 263; No. 50, p. 329. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

A. DAM OF AMITY CANAL ON ARKANSAS RIVER.

B. HEAD GATE OF AMITY CANAL.

Discharge of Arkansas River near Lamar.

[Altitude, 3,592 feet.]

AT HEAD OF AMITY CANAL, AS FURNISHED BY E. R. BANNISTER, HEADGATE KEEPER.

Month.	1898.		1899.		1900.	
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.
January					239	14,696
February					280	11,552
March					170	10,453
April					2,973	176,906
May					4,469	274,788
June			655	38,975	3,290	195,769
July			1,870	114,982	280	17,217
August	211	12,974	884	54,355	89	5,472
September	23	1,369	74	4,403	22	1,309
October	54	3,320	87	5,349	20	1,230
November	265	15,769	249	14,817	109	6,486
December	248	15,249	131	8,055	[a] 150	9,223

[a] Approximate.

AT LAMAR BRIDGE,[a] ESTIMATED BY J. B. TRAXLER, WATER COMMISSIONER, DISTRICT NO. 67.

Day.	1899.		
	March.	April.	May.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*
1	3,000	40	12
2	4,000	40	12
3	4,000	35	12
4	2,500	35	12
5	2,000	30	12
6	1,500	25	12
7	1,200	25	12
8	1,000	25	12
9	800	20	12
10	800	15	12
11	1,500	16	12
12	1,500	16	12
13	1,200	15	12
14	1,000	18	14
15	1,000	20	15½
16	1,000	15	5
17	1,000	15	5
18	800	15	5
19	400	15	5

[a] Total amount of water in district March 13, 250 second-feet; April 3, 225 second-feet; April 16, 175 second-feet; April 25, 120 second-feet; April 30, 75 second-feet; May 5, 180 second-feet; May 10, 100 second-feet; May 13, 200 second-feet; May 14, 150 second-feet; May 16, 230 second-feet; May 18, 325 second-feet; May 20, 308 second-feet.

Discharge of Arkansas River near Lamar—Continued.

AT LAMAR BRIDGE, ESTIMATED BY J. B. TRAXLER, WATER COMMISSIONER, DISTRICT NO. 67—Continued.

Day.	1899.		
	March.	April.	May.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*
20	300	15	5
21	300	15	.....
22	200	15	.....
23	150	15	.....
24	100	15	.....
25	75	15	.....
26	50	15	.....
27	40	12	.....
28	35	12	.....
29	35	12	.....
30	35	12	.....
31	40	.....	.....

Discharge measurements made on Arkansas River at Lamar.

Date.	Hydrographer.	Discharge.	Remarks.
1889.		*Sec.-ft.*	
May 26	F. H. Newell	300	At Lamar.
July 19	.....do	15,000	Do.
July 22	.....do	851	Do.
Aug. 3	.....do	284	Do.
Aug. 7	.....do	187	Do.
1899.			
May 31	A. L. Fellows	249	At Amity canal.
June 18	.....do	114	Do.
1900.			
Apr. 7	.....do	8,890	At Lamar.

PURGATORY RIVER AT TRINIDAD.

This station was located May 1, 1896, in the town of Trinidad, the gage rod being attached to the cylindrical pier at the west end of the Las Animas Street bridge. The station was, however, discontinued July 31, 1899, the greater portion of the water of the river being taken out at points above the station, and the channel being shifting and the results unreliable. A more favorable location would be at a point about 9 miles above the town, near the mouth of the canyon, and above where the most of the water is taken out for irrigation. A station at this point would also have the added advantage that it would furnish

data concerning the flow that might be used for storage, as there are important reservoir sites situated above this point.[a]

Estimated monthly discharge of Purgatory River at Trinidad.

[Altitude, 5,990 feet; drainage area, 742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1896.						
May	113	45	67	4,120	0.09	0.10
June	780	0	60	3,570	.08	.09
July	4,600	8	342	21,029	.46	.53
August	1,657	0	76	4,673	.10	.12
September	554	0	73	4,344	.10	.11
October	189	18	71	4,366	.10	.12
November	60	25	35	2,083	.05	.06
December			[b]40	2,460	.05	.06
1897.						
January			[b]40	2,459	.05	.06
February			[b]50	2,777	.07	.07
March			[b]50	3,074	.07	.08
April	327	68	165	9,818	.22	.24
May	1,412	327	731	44,947	.99	1.14
June	1,534	189	403	23,980	.54	.60
July	1,657	30	250	15,372	.34	.39
August	2,023	10	282	17,339	.38	.44
September	385	30	97	5,772	.13	.14
October	104	54	60	3,689	.08	.09
November	54	30	42	2,499	.06	.07
December			[b]35	2,152	.05	.06
1898.						
May	882	109	264	16,233	.36	.41
June	1,282	109	377	24,433	.51	.57
July	1,147	81	259	15,925	.35	.40
August	752	42	181	11,129	.24	.28
September	1,282	42	173	10,294	.23	.26
October	58	31	39	2,398	.05	.06
November	42	36	39	2,321	.05	.06
1899.						
April	193	32	.82	4,879	.11	.12
May	230	52	110	6,764	.15	.17
June	492	4	71	4,225	.10	.11
July	2,362	16	443	27,239	.60	.69

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineer of Colorado: Eighth, p. 460; Ninth, p. 381; Tenth, p. 319. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 231; Nineteenth, Part IV, p. 358; Twentieth, Part IV, p. 340; Twenty-first, Part IV, p. 235; Water-Supply and Irrigation Papers, No. 16, p. 123; No. 28, pp. 113, 116, and 117; No. 37, p. 263; No. 39, p. 450. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 119.

[b] Estimated.

Discharge measurements made on Purgatory River at Trinidad.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
Sept. 24	A. P. Davis		86
1896.			
Apr. 27	F. Cogswell	3.20	88
June 4	.....do	3.15	72
July 11	.....do	3.20	66
Sept. 14	.....do	3.50	30
Oct. 12	.....do	3.70	48
Nov. 16	C. C. Babb	3.60	24
1897.			
May 22	F. Cogswell	4.25	677
June 17	.....do	4.10	386
July 15	.....do	3.90	189
Sept. 23	P. J. Preston	3.60	49
Nov. 13	F. Cogswell	3.55	46
1898.			
Apr. 28	A. L. Fellows	3.90	150
July 27	.....do	3.90	149
Aug. 29	.....do	3.60	45
Aug. 6	C. W. Beach	3.76	101
Oct. 28	A. L. Fellows	3.40	31
1899.			
Apr. 28	.....do	3.60	52
July 12	.....do	3.30	4

MISCELLANEOUS GAGINGS.

A number of miscellaneous gagings have been made at different times at different points upon the Arkansas and its tributaries, which have been compiled, so far as they are obtainable, from the various sources already cited, and are presented in the following table. Stations have not been maintained at the points mentioned, or if maintained at all have been irregularly kept, and the records have been so unsatisfactory that it is thought best not to publish the gage heights or to approximate the discharge, the data necessary for computing the rating tables being insufficient.

Miscellaneous discharge measurements, Arkansas River and tributaries.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
				Sec.-ft.
Sept. 26, 1893	F. H. Newell	Arkansas	Byron	0
Sept. 24, 1894	A. P. Davis	do	Hayden	114
Sept. 29, 1897	P. J. Preston	do	Manzanola	208
May 18, 1898	C. W. Beach	do	do	847
June 13, 1898	do	Purgatory	J. J. ranch	37
Aug. 5, 1898	do	do	do	60
Sept. 15, 1898	do	Arkansas	Manzanola	208

Discharge measurements made on Arkansas River at La Junta.

Date.	Hydrographer.	Discharge.
1893.		*Sec.-ft.*
Sept. 27	F. H. Newell	24
1894.		
May 21	F. H. Newell	157
June 7	do	15,000
June 8	do	9,500
Oct. 5	do	55
1895.		
Feb. 6	F. H. Newell	182
May 19	do	658
Dec. 2	do	455
1897.		
Sept. 12	P. J. Preston	0
1899.		
May 30	A. L. Fellows	246
June 13	do	857
June 20	do	1,181

Discharge of Arkansas River at La Junta.

[Drainage area, 12,200 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
May 20 to 31	1,960	605	1,089	66,973	0.09	0.10
June	2,620	825	1,355	80,622	.11	.12
July	2,290	345	844	51,906	.07	.08
August	1,630	55	435	26,752	.04	.04

SEEPAGE MEASUREMENTS ON ARKANSAS RIVER.

A series of seepage measurements have been made upon Arkansas River for the purpose of determining the return flow. These have been carried on under the direction of Prof. L. G. Carpenter, of Fort Collins, who has published a bulletin upon the subject.

The table below is compiled from data given in the Ninth Biennial Report, page 308, of the State engineer's office of Colorado, as furnished by Professor Carpenter:

Seepage measurements of Arkansas River.

[In second-feet.]

Place.	Distance (miles).	1897.		1898.	
		Gain.	Loss.	Gain.	Loss.
Canyon to Bessemer ditch	33	54.40	.....	55.17	.....
Bessemer to Pueblo	10	.....	42.18	.....	15.96
Pueblo to Orchard Grove	8	.....	9.40	19.41	.....
Orchard Grove to Boone	16	103.47	.....	20.30	.....
Boone to Nepesta	10	40.44	.....	.....	17.65
Nepesta to Otero canal	8	.....	5.78	.....	11.00
Otero canal to Apishapa Creek	7	16.90	.....	18.15	.....
Apishapa Creek to Rockyford	16½	30.55	.....	21.21	.....
Rockyford to Fort Lyon canal	9	35.59	.....	22.39	.....
Fort Lyon canal to La Junta	3	13.04	.....	8.20	.....
La Junta to Jones ditch	11	10.85	.....	14.76	.....
Jones ditch to Las Animas	9	28.51	.....	20.08	.....
Las Animas to Fort Lyon	6	38.14	.....	13.26	.....
Fort Lyon to Caddoa	11	3.63	.....	.....	.16
Caddoa to Amity canal	10	.....	.....	.....	6.64
Amity to Lamar	11	.....	.....	6.68	.....
Lamar to Holly	30	13.21	.....	14.20	.....
Holly to Coolidge, Kans	7	.....	.....	0	.....
Total	215	387.43	57.36	243.81	51.41
Unreliable	.....	57.36	.....	51.41	.....
Gain	.....	330.07	.....	192.40	.....

NOTE.—Counting the unreliable measurement to gain as in 1898, the gain in 1897 would be 250 second-feet.

RIO GRANDE DIVISION.

DRAINAGE.

Descriptions of the Rio Grande drainage have been given in former reports, but a short résumé is here presented for the convenience of those who do not care to look up the former records.[a]

The Rio Grande and its tributaries drain the mountainous area south and east of the Continental Divide in southwestern Colorado, the principal streams flowing from the east side of the Needle Mountains and from the south and east side of the San Juan Range. Important streams also flow from La Garita Mountains in Saguache and Mineral counties. The main stream flows in an easterly direction for about 75 miles, receiving numerous tributaries from the mountainous region through which it flows. At the town of Del Norte the valley broadens into what is known as the San Luis Valley; thence the stream flows southeastward and southward for about the same distance to a point about 20 miles southeast of Antonito, where it crosses the State line. From the time the river leaves Del Norte but few streams of importance flow into it, as nearly all of those that issue from the mountains lose their waters in the plains before they reach the main stream. This is particularly true of the drainage north and east of the river from the Cochetopa Hills and the Sangre de Cristo Range. Although the streams flowing from these mountains are very numerous and carry large volumes of water, yet they furnish no source of supply to the Rio Grande itself, all the water being lost either in the sands or in broad, shallow lakes, until Trinchera Creek, flowing through the Costilla land grant, is reached. This stream, although usually dry, furnishes a supply at different times in the year. On the south and west side of the river, however, many important streams flow from the mountains, which in their higher stages carry large volumes of water to the Rio Grande. Among these are the Alamosa, La Jara, and Conejos. The supply from these streams also is used mostly during summer, so that after the flood stages are past very little water flows from any of these sources into the Rio Grande itself, as most of it is used in the upper part of the valley, and in the late summer very little passes Alamosa, below which place there are but few irrigating canals. During the flood stages, however, great volumes of water

[a] Hayden's Report of 1875, pp. 153 to 167. Publications U. S. Geological Survey: Tenth Annual Report, Part II, p. 65; Eleventh, Part II (see index); Twelfth, Part II, p. 240; Thirteenth, Part III (see index); Fourteenth, Part II, p. 110; Eighteenth, Part IV, p. 245; Nineteenth, Part IV, p. 381; Twentieth, Part IV, p. 355. Bulletins No. 131, p. 41; No. 140, p. 169; Water-Supply and Irrigation Paper No. 37. See also all Biennial Reports of the State Engineers of Colorado for irrigation in this division, and Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 127. For maps see Pl. I of Part II of the fourth and seventh and Pl. V of the fifth report. See also Senate Document No. 229, Fifty-fifth Congress, second session, on the "Equitable distribution of the waters of the Rio Grande."

flow in the Rio Grande itself and several of its tributaries which might be stored and used for the extension of the irrigated area. Farming is carried on extensively among the upper valleys of several of the streams issuing from the mountains north and east of San Luis Valley, but no official measurements have been made upon any of these streams.

On the headwaters of nearly all of the tributaries of the Rio Grande, as well as on the main stream itself, are important reservoir sites, which might be utilized to store water for late use, so as to render crop raising more certain than it is now. Unfortunately, owing to international complications, it has been impossible in the past to make use of these sites, but it is hoped that this restriction will soon be removed, as it is clearly to the advantage of the agricultural interests as a whole that the water should be used to as great an extent as possible along the upper portion of the streams.

The lands drained by the Rio Grande and its tributaries constitute irrigation division No. III. The various districts into which it is divided are No. 20, comprising the Rio Grande drainage, excepting those streams included in separate districts, which are No. 21, covering Alamosa and La Jara creeks with their tributaries; No. 22. Conejos Creek; No. 24, Costilla Creek; No. 25, San Luis Creek; No. 26, Saguache Creek; No. 27, Tuttle, Carnero, La Garita, and all other creeks and their tributaries which have their sources of water supply in the La Garita Mountains and flow eastward into the San Luis Valley; and No. 35, Trinchera Creek.

There are many problems of interest connected with the use of water in the San Luis Valley, among which is the study of loss by evaporation and seepage. Investigation is being carried on in this line by Prof. L. G. Carpenter, already mentioned, of the Colorado State Agricultural College.

STREAM MEASUREMENTS.

Although hydrographic data are most desirable in this valley, but little hydrographic work has been done, owing to the scarcity of funds, both in the office of the State engineer and the United States Geological Survey, so that only three stations have been maintained for any considerable length of time, and of these only one, the station at Del Norte, has been maintained for a length of time sufficient to furnish anything like accurate information concerning the normal flow. The two that have been kept up for shorter periods are a station near the State line, upon the main Rio Grande, and one upon the Conejos, about 10 miles west of the town of Antonito, on the Denver and Rio Grande Railroad.

A. GAGING RIO GRANDE AT DEL NORTE.

B. STATE BRIDGE ACROSS RIO GRANDE NEAR COLORADO STATE LINE.

RIO GRANDE AT DEL NORTE.

This station is located about 3 miles west of the town of Del Norte, above the main canals taking water from the Rio Grande. Records have been kept since the fall of the year 1889 for very nearly the entire time. A steel cable is stretched across the river at this point and the gagings are made by means of a car traveling on the cable, distances being marked on a tag wire, and, at low water, by wading. The channel consists of small bowlders and gravel, and although the sides are not high, the stream has never been known to overflow at this point. The conditions are excellent for good results, as the bed of the stream scours but little, although the fall is comparatively rapid. The station is of great value, as the distribution of water among the numerous consumers is made to depend very largely upon the data obtained as shown on the gage rod. Information is also furnished concerning the supply available for storage in reservoir sites above.

The citizens of San Luis Valley seem to appreciate fully the advantage of this station and have frequently expressed themselves as desiring to see this service extended.[a]

[a] For detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 21 and 40; and Part II, Pl. V; Sixth, p. 38; Seventh, p. 170; Eighth, p. 488; Ninth, p. 385; Tenth, p. 321. Also publications U. S. Geological Survey, Eleventh Annual Report, Part II, pp. 53 and 98; Twelfth, Part II, p. 246; Thirteenth, Part III, p. 99; Fourteenth, Part II, p. 110; Eighteenth, Part IV, p. 246; Nineteenth, p. 383; Twentieth, p. 359; Twenty-first, Part IV, p. 256; Bulletins No. 131, p. 41; Nos. 140 to 170; Water-Supply and Irrigation Papers, No. 11, p. 64; No. 16, p. 127 No. 28, pp. 126, 129, and 130; No. 37, p. 277; No. 39, p. 450; No. 50, p. 347. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 113, 127

Discharge of Rio Grande at Del Norte.

[Altitude, 7,865 feet; drainage area, 1,400 square miles.]

Month.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off.[a] Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	[b] 552	[b] 990	[c] 300	[b] 966	[b] 1,003	[b] 801	[b] 1,293	[bc] 1,000	[bc] 1,377	[b] 1,308	[b] 862	[b] 950	58,413	0.68	0.78
February	.....	[b] 796	[b] 1,294	[c] 300	[bc] 700	[b] 995	[b] 953	[b] 1,258	[bc] 1,000	[bc] 1,472	[b] 1,113	[b] 1,005	[b] 989	54,926	.71	.83
March	.....	487	1,280	316	[bc] 500	[b] 831	638	[b] 1,081	[bc] 1,000	[bc] 1,471	[b] 875	399	[b] 807	49,620	.58	.67
April	.....	913	[b] 1,410	1,047	533	699	[b] 1,883	1,484	1,067	[b] 1,912	617	419	[b] 1,089	64,800	.78	.87
May	.....	4,331	3,285	2,605	1,944	1,798	2,116	2,374	3,537	2,722	1,378	2,854	2,631	161,774	1.88	2.17
June	.....	3,807	4,146	2,187	1,749	802	2,209	821	3,391	4,390	1,091	2,691	2,480	147,570	1.77	1.97
July	.....	1,515	1,693	740	395	292	958	403	1,108	1,643	703	547	908	55,830	.65	.75
August	.....	612	663	444	324	309	720	261	475	509	598	231	467	28,715	.33	.38
September	.....	383	527	263	270	286	454	477	631	319	365	256	384	22,850	.27	.30
October	[c] 278	470	844	259	263	289	435	469	1,472	259	492	343	489	30,067	.35	.40
November	319	478	374	360	278	236	353	310	665	[b] 816	490	253	411	24,456	.29	.32
December	281	[b] 565	[c] 325	[b] 922	[b] 642	288	[b] 1,008	375	[bc] 800	[bc] 1,300	[b] 742	[b] 755	[b] 666	40,950	.48	.55
Mean	292	[b] 1,242	1,403	812	[b] 714	[b] 652	[b] 1,044	[b] 884	1,346	[b] 1,517	814	[b] 884	[b] 1,023	739,971	.73	9.99
Acre-feet, total	.....	900,926	1,014,426	590,219	516,886	471,408	754,931	641,017	945,418	1,094,950	589,293	641,017	.....	.....	.....	.....

[a] The run-off given is for average months and the totals for an average year as calculated from all observations and estimates. Details may be found in the authorities cited.

[b] Probably too high because of ice piling up along the sides of the stream and thus narrowing the channel. It is not likely that the winter flow is even more than 600 second-feet. The totals are carried out, however, as though the observations gave a correct idea of the discharge.

[c] Approximate.

Maximum and minimum discharge and average run-off of Rio Grande at Del Norte for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1890	Oct. 2	307	Apr. 27	5,930	12.06	0.89
1891	Sept. 19	290	May 7	5,650	13.56	1.00
1892	Sept. 26	243	May 24	4,710	7.92	.58
1893	Nov. 8	214	May 19	3,320	6.93	.51
1894	Nov. 27	201	May 17	2,850	6.29	.46
1895	Nov. 21	322	June 12	3,840	10.14	.75
1896	Aug. 21	214	May 3	3,579	8.58	.63
1897	Sept. 1	342	May 27	5,234	13.05	.96
1898	Nov. 9	221	June 3	5,266	14.06	1.08
1899	Sept. 13	268	May 11	2,330	7.87	.58
1900	Aug. 31	163	May 29	5,454	8.55	.63

[a] The run-off, per acre-foot, given is for each entire year, including estimates; the discharge given is for average months and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Discharge measurements made on Rio Grande at Del Norte.

Date	Hydrographer.	Gage height.	Discharge.
1891.		*Feet.*	*Sec.-ft.*
Apr. 10	T. M. Bannon	2.20	527
1892.			
Oct. 27	T. M. Bannon	1.58	274
1894.			
June 13	F. H. Newell	2.68	968
Sept. 27	A. P. Davis	1.52	267
1895.			
June 14	A. P. Davis and F. Cogswell	4.00	2,818
Oct. 13	F. Cogswell	1.80	414
1896.			
June 22	F. Cogswell	1.90	492
July 27	do	1.70	385
Sept. 28	do	2.30	706
Oct. 26	do	1.80	445
1897.			
Apr. 26	F. Cogswell	3.00	1,507
May 17	do	4.05	3,014
May 29	do	5.45	4,898
June 28	do	3.30	1,769
July 26	do	2.00	640
Aug. 30	do	1.55	373
Oct. 25	do	2.66	1,113

Discharge measurements made on Rio Grande at Del Norte.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	[illegible]
Apr. 14	A. L. Fellows	3.27	1,[illegible]
May 18	do	3.23	1,[illegible]
June 23	do	5.25	5,[illegible]
Aug. 25	do	1.86	[illegible]
Oct. 25	do	1.48	[illegible]
1899.			
Apr. 25	A. L. Fellows	2.42	1,[illegible]
May 24	do	2.92	1,[illegible]
June 29	do	2.10	[illegible]
Aug. 21	do	1.58	[illegible]
1900.			
Mar. 30	A. L. Fellows	1.54	[illegible]
May 12	do	3.84	2,[illegible]
June 16	do	3.66	2,[illegible]
Aug. 18	do	1.34	[illegible]

CONEJOS RIVER NEAR LOS MOGOTES.

This stream, the most important tributary of the Rio Grande in Colorado, rises on the eastern slope of the San Juan Range, which forms the western boundary of Conejos County. It flows southeastward as far as the town of Conejos; then, bending northeastward, enters the Rio Grande below the mouth of Trinchera Creek. All of the ordinary flow of this stream is used during the irrigation season but at flood stages and in winter considerable water goes to waste. The station is located about 10 miles west of Antonito, from which town it may be reached by driving. The nearest post-office is at Los Mogotes, about 4 miles from the station, but the observer was always accustomed to get his mail at Antonito. It was established August 25, 1899, and was first located at a wagon bridge crossing the river; but owing to the fact that the rod at that point was maliciously destroyed, the station was removed to a point about 500 yards downstream, where it was attached to a pier projecting into the river near a farmhouse. The channel is fairly good, being of gravel and not particularly liable to either change or overflow. Owing to the removal of the gage from its old station and to the small number of measurements made, but few data are available.

San Antonio River is an important branch of the Conejos, and a few measurements were made upon this stream also, these being given in the list of miscellaneous measurements.[a]

[a] For more detailed information regarding this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 328, and U. S. Geological Survey Water-Supply and Irrigation Papers, No. 37, p. [illegible] and No. 50, p. 348. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. [illegible]

Discharge measurements made on Conejos River near Los Mogotes.

[A. L. Fellows, hydrographer.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
August 25	1.00	76
November 28	2.20	70
1900.		
March 28	1.68	144
May 11	3.10	1,087
June 23	2.30	467
August 17	1.15	33

RIO GRANDE AT CENICERO.

This station is located a short distance north of the boundary line between Colorado and New Mexico, at a point where the river is crossed by a State wagon bridge. It was established July 28, 1899, and has been kept up regularly ever since. Two gage rods are necessary, one for high and the other for low water. The channel is excellent, the bed consisting of bowlders and rock and being subject to but little change, and the banks are high and not liable to overflow. At high water gagings may be made from the bridge, but at low water they are usually made by wading. The station is an important one, as it gives information concerning the entire drainage of the Rio Grande in Colorado and the discharge of the river practically where it enters New Mexico, this information being of value to both Colorado and New Mexico and furnishing important data bearing upon storage and the use of water. The nearest railroad point is Antonito, from which the station may be reached by driving about 15 miles. The nearest post-office is at Eastdale, but the observer has been in the habit of getting his mail at Cenicero, which is on the road between Antonito and the gaging station, about 4 miles from the former.[a]

[a] For more detailed information concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 326; U. S. Geological Survey Water-Supply and Irrigation Papers, No. 37, p. 279; No. 39, p. 450, and No. 50, p. 349.

Estimated monthly discharge of Rio Grande at Cenicero.

[Drainage area, 7,695 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
July	170	12	42	2,582	0.005	[illegible]
August	129	20	53	3,259	.007	[illegible]
September	423	31	102	6,069	.013	[illegible]
October	170	65	117	7,194	.015	[illegible]
November	297	170	259	15,412	.034	[illegible]
December	381	170	318	19,553	.041	[illegible]
Last 6 months of the year	423	12	148	54,069	.019	[illegible]
1900.						
January	1,134	594	638	39,229	.083	[illegible]
February	1,134	22	759	42,153	.099	[illegible]
March	1,134	236	583	35,847	.076	[illegible]
April	504	183	350	20,826	.045	[illegible]
May	3,294	414	1,430	87,927	.186	[illegible]
June	3,294	79	1,424	84,734	.185	[illegible]
July	58	22	29	1,783	.004	[illegible]
August	22	16	22	1,353	.003	[illegible]
September	43	16	31	1,845	.004	[illegible]
October	58	31	31	2,275	.005	[illegible]
November	504	58	155	9,223	.020	[illegible]
December	594	414	571	35,109	.074	[illegible]
The year	3,294	16	502	362,304	.065	[illegible]

Discharge measurements made on Rio Grande at Cenicero.

[A. L. Fellows, hydrographer.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
June 28	0.90	[illegible]
August 24	1.00	[illegible]
November 28	1.80	[illegible]
1900.		
March 29	1.60	[illegible]
May 10	2.00	[illegible]
June 22	1.80	[illegible]
August 16	.75	[illegible]

MISCELLANEOUS MEASUREMENTS.

A table is given below of the miscellaneous measurements of which records are obtainable that have been made in the Rio Grande drainage basin in Colorado. These are of importance, as they furnish information concerning the flow of the various streams at stated times and given points.

Miscellaneous discharge measurements on Rio Grande and tributaries.

Date.	Hydrographer.	Stream.	Locality.	Discharge in second-feet.
Sept. 28, 1894	A. P. Davis	Rio Grande	Alamosa	10
June 16, 1895	F. Cogswell	do	do	1,176
Oct. 14, 1895	do	do	do	92
May 19, 1896	do	do	do	132
June 23, 1896	do	do	do	32
June 24, 1896	F. F. Anderson	Conejos	Los Mogotes	67
July 26, 1896	F. Cogswell	do		3
Aug. 20, 1899	A. L. Fellows	do	6 miles below Alamosa.	17
Aug. 23, 1899	do	do	½ mile above Alamosa.	10
May 11, 1900	do	San Antonio	Antonito	473
June 22, 1900	do	do	do	4

SEEPAGE MEASUREMENTS.

The seepage measurements given below were made under the direction of Prof. L. G. Carpenter, of Fort Collins, and were furnished by him to the State engineer of Colorado. The table is from the Tenth Biennial Report, pages 219 and 221. Professor Carpenter expects to publish a bulletin on these measurements shortly.

Seepage measurements on Rio Grande, 1900.

[In second-feet.]

Place of measurement.	Date.	Section inflow.	Section outtake.	River.	Section gain or loss.	Total gain or loss.
Railroad station at South Fork	Aug. 30	0.85	33.41	194.24	.....	.....
United States Geological Survey gaging station	Aug. 31	.....	.....	209.83	48.15	48.[illegible]
Do	Aug. 20	.....	146.61	249.06	.....	.....
Above Del Norte canal	do	.....	.....	176.50	25.95	22.[illegible]
Do	Aug. 21	.....	32.11	178.90	.....	.....
At Off's	do	.....	.....	168.48	21.69	43.[illegible]
Do	Aug. 22	.....	47.19	156.22	.....	.....
Below Prairie canal	do	.31	.....	99.29	-10.05	33.[illegible]
Do	Aug. 23	4.33	96	108.91	.....	.....
Below Monte Vista bridge	do	.....	.....	14	—3.24	30.[illegible]
Do	Aug. 24	.....	30.29	14.30	.....	.....
Below San Luis canal	do	5.21	14.24	5.90	21.89	52.[illegible]
Below Hickory-Jackson ditch	do	.....	.....	10.65	13.98	66.[illegible]
Do	Aug. 25	.....	10.69	11.55	.....	.....
Below Alamosa	do	.....	.....	1	.14	66.[illegible]
Do	Aug. 27	.....	.....	1.01	.....	.....
Above mouth of Conejos River	do	14.33	.....	1.35	.24	66.[illegible]
Below Conejos (North Branch)	do	6.90	.....	15.33	—.35	66.[illegible]
Below Las Sauces	do	.....	.....	23.98	1.75	68.[illegible]
Do	Aug. 28	.....	.....	22.31	.....	.....
Above State bridge	do	.....	.....	17.22	-5.09	63.[illegible]

Seepage measurements on Conejos River, 1900.

[In second-feet.]

At State gaging station	Aug. 31	.....	.....	24.65	.....	.....
Above San Juan bridge	do	.....	1.97	24.77	2.09	.....
At bridge	do	.....	2.15	.50	--22.12	—2[illegible]
Above Cerritos	Aug. 30	0.77	.....	.80	.30	—19.[illegible]
Below San Antonio Creek	do	.....	3.32	.55	--1.02	—20.[illegible]
At McIntire place	do	.....	.....	3.88	6.65	—14.[illegible]
Do	Aug. 29	.....	24	4.33	.....	.....
Below McIntire spring	do	.....	14.19	31.33	3	—11.[illegible]
Two hundred feet above bridge	do	.....	.....	24.02	6.88	-4.[illegible]

SAN JUAN DIVISION.

IRRIGATION.

San Juan River rises in the San Juan Mountains, the small streams at the head flowing westward, opposite to the direction taken by the branches of the Conejos. The country is generally mountainous and rough, and but little irrigation is practiced along the stream, except in the bottom lands adjacent to the channel. The stream flows but a short distance through Colorado before entering New Mexico, through which it flows for about 100 miles, then crosses the southwest corner of Colorado again, and flows thence through Utah to its junction with the Colorado at Henry Mountain. The principal tributaries flowing from Colorado into this river are the Piedra, Los Pinos, Florida, Las Animas, La Plata, and Mancos, all of which flow through comparatively narrow valleys, crossing the line into New Mexico before the San Juan itself is reached. A large portion of this country has been but very recently opened to settlement, as it remained a part of the Southern Ute Reservation until 1899, when the western half of that reservation was thrown open to settlement, and a number of settlers have come in. A very considerable portion of the most desirable lands had, however, been taken by the Indians in severalty. There are a number of excellent mesas of good farming land which will undoubtedly be eventually irrigated. A number of surveys have already been made of canal lines to cover these tracts, which will be speedily pushed to completion.

DRAINAGE.

San Juan River and its tributaries drain practically all of that portion of the southwestern corner of Colorado which comprises the Durango Land District, except a portion of the northern part, which is drained by the Dolores River, a tributary of the Grand. The northeastern quarter of this district is very mountainous, the principal tributaries of the San Juan having their headwaters among lofty mountain peaks and mountain parks of high altitude. Little irrigation is practiced in the upper valleys of any of the streams of this district, except for raising hay, above a height of about 7,000 feet, from which altitude the level of this district in Colorado runs down to about 4,500 feet. In the lower valleys agriculture is extensively practiced, and nearly all kinds of crops that may be raised in temperate climates are cultivated. A very large portion of the division will undoubtedly be irrigated eventually, and water will be used extensively for the development of power, so that the supply of water in many of the streams will prove inadequate without a comprehensive system of storage. There are fortunately a number of excellent reservoir sites on the headwaters of a number of the streams, particularly upon the San Juan, Piedra, Los Pinos, and Florida.

The drainage area of the San Juan and its tributaries, while constituting irrigation division No. IV in accordance with the laws of Colorado, is practically composed of a number of strictly independent districts, as each one of the main tributaries crosses the line between Colorado and New Mexico before it empties into the San Juan, and hence the use of the water of the various streams does not conflict to any great extent. The irrigation districts that compose the division and the streams that furnish their supply of water are No. 29, comprising the territory drained by the headwaters of the San Juan and the Piedra; No. 31, the Los Pinos district; No. 30, the Las Animas district; No. 33, the La Plata district; No. 34, the Mancos district, and No. 32, the Montezuma Valley district, the latter being practically a part of the Grand River division.[a]

STREAM MEASUREMENTS.

A number of stations have been maintained at different times in this division, those for which separate tables are given being situated near Arboles, on the San Juan and Piedra rivers; at Ignacio, on Los Pinos River; at Stewart's ranch, on Florida River; at Durango, on Animas River; and at Mancos, on Mancos River.[b]

SAN JUAN RIVER AT ARBOLES.

This station is located a short distance west of the old Arboles railroad station on the Denver and Rio Grande Railroad, where a footbridge was constructed by the Survey across the river for the purpose. The channel is not favorable to accurate measurements, the bridge crossing the river at a point where there is a deep hole and the left bank being liable to overflow. The bed of the channel is somewhat sandy and shifting, gravel bars forming at times along the bends of the river and again being displaced at the next high water. Measurements were made from the footbridge above mentioned. The station was valuable as furnishing information concerning the flow of the San Juan into New Mexico and the amount of water available for the use of the Indians along its border, as well as for use on tracts of the public domain.

The well-known Pagosa Mineral Springs are situated upon the headwaters of the San Juan, and a railroad has recently been constructed into this territory.[c]

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[a] For detailed information concerning the agriculture of this region, see the State Engineers' Reports.

[b] For more detailed information concerning this drainage basin, see Hayden's Report of 1875. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 278; Nineteenth, Part IV, p. 409; Twentieth, Part IV, p. 400; Bulletin, No. 140, p. 195; Water-Supply and Irrigation Paper No. 38, p. 307. Also Tenth Biennial Report of the State Engineer of Colorado, p. 330. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 90–135.

[c] For more detailed data concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 498; Ninth, p. 388; Tenth, p. 331. Also publications U. S. Geological Survey: Eighteenth Annual Reports, Part IV, p. 279; Nineteenth, Part IV, p. 409; Twentieth, Part IV, p. 401. Twenty-first, Part IV, p. 297; Bulletin No. 140, p. 195; Water-Supply and Irrigation Papers No. 11, p. 71; No. 16, p. 144; No. 28, pp. 138, 142, and 145; No. 38, p. 307; No. 39, p. 451. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 102.

A. GAGING STATION ON SAN JUAN RIVER AT ARBOLES.

B. GAGING STATION ON PIEDRA RIVER AT ARBOLES.

[Altitude, 5,998 feet; drainage area, 1,391 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
April	.....	1,123	1,987	1,498	[b] 934	1,383	82,294	0.99	1.10
May	.....	1,635	3,393	1,884	917	1,957	120,331	1.40	1.61
June	[b] 1,261	444	2,311	2,390	550	1,391	82,770	1.00	1.11
July	635	256	685	1,022	523	624	38,368	.45	.52
August	422	189	303	255	385	311	19,123	.22	.25
September	220	309	607	123	219	296	17,613	.21	.23
October	206	250	1,019	99	.....	394	24,226	.28	.32
November	197	210	396	83	.....	222	13,210	.16	.18
Mean	490	552	1,338	918	588	822	397,935	.59	5.32
Acre-feet for period recorded	177,785	267,180	647,576	444,324	213,561	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

[b] Approximate, only part of month.

Maximum and minimum discharge and average run-off of San Juan River at Arboles for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 11	135	June 19	1,770	0.39	0.5[illegible]
1896	Aug. 22	136	May 6	2,615	.45	.4[illegible]
1897	Aug. 31	182	May 20	4,423	1.07	.[illegible]
1898	Sept. 25	83	June 24	3,255	.73	.6[illegible]
1899	Sept. 8	96	May 13	1,976	.47	.4[illegible]

[a] The run-off given in the horizontal lines is the amount for that part of each year covered by the record and the depths in inches is for a period of thirty days at the rate given as the mean in second-feet per square mile for the period covered. The discharge given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

Discharge measurements made on San Juan River at Arboles.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 21	F. Cogswell	7.30	1,5[illegible]
Aug. 30	do	6.20	[illegible]
Oct. 11	do	5.80	21[illegible]
Nov. 25	do	5.90	2[illegible]
1896.			
May 16	F. Cogswell	6.65	7[illegible]
June 21	do	5.90	[illegible]
July 25	do	6.00	[illegible]
Sept. 26	do	6.15	[illegible]
Oct. 24	do	6.20	[illegible]
1897.			
Apr. 25	F. Cogswell	8.30	2,7[illegible]
May 16	do	8.80	3,31[illegible]
June 27	do	7.60	1,[illegible]
July 25	do	6.50	[illegible]
Aug. 29	do	5.80	[illegible]
Sept. 26	do	8.00	2,[illegible]
Oct. 24	do	6.90	[illegible]
1898.			
Apr. 12	A. L. Fellows	7.30	1,[illegible]
May 17	do	7.42	1,[illegible]
June 21	do	8.10	2,5[illegible]
Aug. 8	G. H. Matthes	6.30	[illegible]
Aug. 21	A. L. Fellows	6.05	[illegible]
Oct. 23	do	5.80	[illegible]

Discharge measurements made on San Juan River at Arboles.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 23	A. L. Fellows	7.00	1,286
May 22	.....do	6.60	737
June 26	.....do	6.15	277
Nov. 26	.....do	5.75	127

PIEDRA RIVER AT ARBOLES.

This tributary of San Juan River rises among the San Juan Mountains in Hinsdale and Mineral counties, in southern Colorado, and flows in a nearly southerly direction to its junction with the San Juan about one-quarter of a mile west of the old Denver and Rio Grande Railroad station at Arboles. Very little irrigation is practiced upon this stream, and that little is along the lower course of the river. It is possible, however, to take water out for the irrigation of mesa lands lying along the west side of the stream between it and Los Pinos River. The value of the information derived from the maintenance of this station is due to the fact that it is an important source of supply for the Indians along its borders and for the owners of lands along the San Juan below their junction.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 504; Ninth, p. 390; Tenth, p. 334. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 281; Nineteenth, Part IV, p. 411; Twentieth, Part IV, p. 402; Twenty-first, Part IV, p. 298; Bulletin No. 140, p. 196; Water-Supply and Irrigation Papers No. 11, p. 71; No. 16, p. 145; No. 28, pp. 139, 142 and 145; No. 38, p. 308; No. 39, p. 452.

Discharge of Piedra River at Arboles.

[Altitude, 5,998 feet; drainage area, 670 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	.....	[b] 804	1,460	978	[c] 380	906	53,911	1.352	1.51
May	([d])	1,048	2,025	966	315	1,089	66,960	1.625	1.88
June	432	229	1,189	1,211	168	646	33,440	.964	1.07
July	346	111	296	585	141	296	18,200	.442	.51
August	200	59	106	149	180	139	8,547	.207	.24
September	115	347	399	89	49	200	11,901	.299	.33
October	125	175	840	70	.....	303	18,631	.452	.52
November	93	121	241	37	.....	123	7,319	.184	.20
Mean	219	362	820	511	206	463	223,909	.691	6.26
Acre-feet for period recorded	71,610	167,298	396,988	247,416	90,798	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

[b] April 12 to 30 inclusive.

[c] April 23 to 30 inclusive.

[d] May 19 to 30 inclusive.

Maximum and minimum discharge and average run-off of Piedra River at Arboles for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 6	60	July 12	6.70	0.37	0.327
1896	Aug. 11	23	May 6 Sept. 24	2,066 3,000	.60	.540
1897	Aug. 25	65	May 7	2,398	1.36	1.224
1898	Nov. 13	27	Apr. 27	1,599	.84	.763
1899	Sept. 6	25	May 13	643	.35	.307

[a] The run-off given is the amount for that part of each year covered by the records and the depth in inches for a period of thirty days as the rate given as the mean in second-feet per square mile for that period covered. The discharge given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

Discharge measurements made on Piedra River at Arboles.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 21	A. P. Davis and F. Cogswell	3.90	606
Aug. 30	F. Cogswell	3.20	235
Oct. 11	do	2.90	140
Nov. 25	do	2.80	115
1896.			
May 18	F. Cogswell	3.90	544
June 20	do	2.90	109
July 24	do	3.05	189
Sept. 27	do	3.70	465
Oct. 25	do	3.00	179
1897.			
Apr. 24	F. Cogswell	5.20	1,429
May 15	do	5.65	1,629
June 26	do	4.20	677
July 24	do	3.10	230
Aug. 28	do	2.60	65
Sept. 25	do	4.15	675
Oct. 23	do	4.00	586
1898.			
Apr. 13	A. L. Fellows	4.80	1,158
May 16	do	4.52	937
June 22	do	5.10	1,315
Aug. 8	G. H. Matthes	3.10	195
Aug. 24	A. L. Fellows	3.05	186
Oct. 24	do	2.60	52

Discharge measurements made on Piedra River at Arboles—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 23	A. L. Fellows	3.80	499
May 22	do	3.40	279
June 26	do	2.90	111
Nov. 26	do	2.80	88

LOS PINOS RIVER AT IGNACIO.

This stream drains the country near the western end of the San Juan Range and the southern slope of the Needle Mountains. It flows in a southerly direction for about 50 miles, crossing the Colorado line about 5 miles south of La Boca, on the Denver and Rio Grande Railroad. The valley is in general wider than the valleys of the Piedra and San Juan, and irrigation is more extensively practiced along the borders of the stream. A number of canals have been constructed by the Government for the benefit of the Indians located on the bottom lands. Several irrigation canals have also been projected, and surveys have been made by private parties for the purpose of taking out water to the adjacent mesas. The station is important as giving information concerning the supply of water available for the use of the Indians and of white settlers as well. The Indians have in general taken lands in severalty in the first bottom lands of the stream, but since the reservation was thrown open many white settlers have filed on lands higher up. The normal supply of this stream will probably eventually prove insufficient for irrigation, and this may be true even with storage. There are, however, some very fine reservoir sites upon the headwaters of the stream which may be used.

The gaging station is located at the subagency, about 2 miles north of the station of the Denver and Rio Grande Railroad. The channel is fairly suitable at this point, being of gravel and bowlders, and has suffered little change since the station was established. Measurements are usually made at the wagon bridge, to which the rod is attached, but may at times of low water be made by wading. The channel is fairly stable at this point, the banks, although low, not being particularly liable to overflow. Records have been irregular and unsatisfactory, but a table is compiled from the few that have been sent in.[a]

[a] For more detailed data concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 336. Also publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 299; Water-Supply and Irrigation Papers, No. 38, p. 309; No. 39, p. 452; No. 50, p. 380.

Estimated monthly discharge of Los Pinos River at Ignacio.

[Altitude, 6,422 feet; drainage area, 450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 23 to 30			479	29,693	1.11	1.24
May	947	180	530	32,588	1.18	1.36
June	605	264	469	27,907	1.04	1.16
July	662	124	289	17,770	.64	.74
August	1,346	49	349	21,459	.77	.89
September	264	36	62	3,689	.14	.16
October	292	36	127	78,088	.28	.32
November	124	89	103	6,129	.23	.26
December 1 to 21	89	49	59	3,628	.13	.15
1900.						
January	101	61	82	5,042	.19	.22
February	61	61	61	3,388	.13	.13
March	141	61	94	5,780	.21	.24
April 1 to 7	193	101	166	9,878	.36	.40
May 9 to 26	1,326	785	998	61,365	2.22	2.56

Discharge measurements made on Los Pinos River at Ignacio.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Apr. 22	3.20	437
May 20	3.40	577
June 25	2.80	244
Nov. 25	2.60	124
1900.		
Mar. 26	2.60	137
May 8	3.50	604
Aug. 14	2.00	25

FLORIDA RIVER AT STEWART'S RANCH, NEAR DURANGO.

This stream is a tributary of Animas River, and drains the country immediately west of that drained by the Los Pinos. Irrigation is extensively practiced along this stream, particularly along its lower course, and the supply, being insufficient, is exhausted early in the irrigation season. Owing to the fact that there are large tracts of land

along the stream that might be cultivated if there were enough water, a project has been considered for storing water in the upper portion of the drainage basin. The land is particularly valuable, being located near the city of Durango and being at such an altitude that wheat and other grains may be most successfully raised. The station was maintained for a portion only of one summer, with a view to ascertaining the high-water discharge. The data thus derived are given in full.[a]

Estimated monthly discharge of Florida River at Durango.

[Drainage area, 136 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
May 21 to 31	.....	.....	139	8,547	1.02	1.18
June	121	12	68	4,046	.50	.56
July	211	6	45	2,767	.33	.38

The only gagings made in the year 1899 are as given below:

Discharge measurements made on Florida River at Durango.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
May 19	2.25	236
June 24	.70	9

ANIMAS RIVER AT DURANGO.

This stream is the largest tributary of the San Juan, and derives its water from the high mountains above Silverton, draining portions of the Needle and La Plata mountains, in addition to the area south of Mount Sneffels and Red Mountain. The country drained by this stream and its tributaries is generally very mountainous down to a point about 12 miles above the city of Durango, where the valley broadens out to such an extent that irrigation is extensively practiced. The supply of water is probably more than adequate to meet all demands for irrigation, although a number of projects are being con-

[a] For more detailed data concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 340. Also publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 300; Water-Supply and Irrigation Papers, No. 38, p. 311; and No. 39, p. 452. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

sidered with a view to using the waters of this river and of its tributaries for the development of power, both directly and through the transmission of electricity. An important project has also been undertaken for the construction of a large canal using the water of the Animas River in New Mexico.

The station is located at the wagon bridge, a short distance west of the railroad station at Durango. In 1889 a new bridge was constructed, rendering the new station much more satisfactory than the old one had been. The stream is usually gaged from the wagon bridge, but may at very low water be gaged by wading. The channel is of bowlders, and is fairly stable, although occasional changes occur. The banks are high and not liable to overflow.[a]

[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 510; Ninth, p. 392; Tenth, p. 342. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 283; Nineteenth, Part IV, p. 414; Twentieth, Part IV, p. 403; Twenty-first, Part IV, p. 301; Bulletin No. 140, p. 198; Water-Supply and Irrigation Papers, No. 11, p. 72; No. 16, p. 146; No. 28, pp. 139, 142, and 145; No. 38, p. 310; No. 39, p. 452; No. 50, p. 383. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

Estimated mean discharge of Animas River at Durango.

[Altitude, 6,551 feet; drainage area, 812 square miles.]

Month	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
									Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
January	.....	.....	[b]310	[b]378	.....	[b]179	389	23,919	0.48	0.55
February	.....	.....	[b]284	[b]267	.....	[b]133	261	14,495	.32	.33
March	.....	.....	[b]374	[b]306	.....	[b]224	301	18,508	.37	.43
April	.....	[c]1,634	2,608	1,510	584	335	1,334	79,379	1.64	1.83
May	.....	2,326	4,498	1,765	1,730	2,183	2,500	153,719	3.08	3.55
June	[d]646	875	3,218	3,431	1,797	1,990	1,993	118,592	2.45	2.73
July	388	349	1,120	1,364	668	409	716	44,025	.88	1.01
August	510	199	534	364	691	179	413	25,394	.51	.59
September	363	1,004	875	263	276	231	502	29,871	.62	.69
October	307	475	1,385	161	297	252	480	29,514	.59	.68
November	246	274	553	158	267	205	289	17,197	.36	.40
December	[b]251	[b]216	430	[b]250	[b]212	[b]272	272	16,725	.34	.39
Mean	387	816	1,349	851	724	550	788	571,338	.97	13.18
Acre-feet for period recorded	149,760	426,908	979,347	615,997	388,900	398,215	.....	.....	.....	.....

[a] The run-off given in the above table is for normal months and the totals for a normal year as derived from the observations. Details may be found in the authorities cited.

[b] Approximate.

[c] April 12 to 30, inclusive.

[d] June 20 to 30, inclusive.

Maximum and minimum discharge and average run-off of Animas River at Durango for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Aug. 12, Dec. 15	208	Aug. 14	990	3.82	0.48
1896	Aug. 26	138	Sept. 24	[b] 7,800	10.18	1.00
1897	Aug. 27	325	May 25	5,870	22.61	1.66
1898	Nov. 19	125	June 23	4,677	14.25	1.05
1899	Apr. 6	138	May 14	3,240	9.09	.89
1900	Feb. 17	122	May 28	3,830	9.58	.69

[a] The run-off given is the amount for that part of each year covered by the records and the depth in inches for the time. Details may be found in the authorities cited.
[b] Approximate.

Discharge measurements made on Animas River at Durango.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 18	F. Cogswell	6.50	1,893
Aug. 29	do	5.80	543
Oct. 10	do	5.40	328
Nov. 24	do	5.20	260
1896.			
May 15	F. Cogswell	6.35	1,063
June 19	do	5.80	590
July 23	do	5.50	360
Sept. 25	do	7.40	2,566
Oct. 23	do	5.50	414
1897.			
Apr. 23	F. Cogswell	7.75	2,176
May 14	do	9.20	4,786
June 25	do	7.85	2,534
July 23	do	6.10	997
Aug. 27	do	5.10	328
Sept. 24	do	6.05	905
Oct. 22	do	6.50	1,121
1898.			
Apr. 11	A. L. Fellows	6.50	1,356
May 15	do	7.25	1,797
June 20	do	8.55	3,475
Aug. 5	G. H. Matthes	5.20	414
Aug. 22	A. L. Fellows	5.07	284
Oct. 22	do	4.70	160

Discharge measurements made on Animas River at Durango—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 21	A. L. Fellows	7.50	698
May 19	.....do	9.45	2,635
June 24	.....do	8.10	1,256
Sept. 28	.....do	6.52	223
Nov. 25	.....do	6.50	207
1900.			
Mar. 26	A. L. Fellows	6.60	246
May 9	.....do	8.65	1,614
June 25	.....do	8.80	1,740
Aug. 13	.....do	6.45	169

MANCOS RIVER AT MANCOS.

Mancos River rises on the southwestern slopes of the La Plata Mountains and flows in a generally southwesterly direction, emptying into the San Juan at a point about 6 miles east of the southwest corner of the State of Colorado, or the Four Corners. The upper portion of the drainage is mountainous, and little irrigation is possible until the valley broadens out in the vicinity of the town of Mancos, where all of the ordinary flow of the stream is used. Enough water goes to waste, however, at high stages to irrigate probably all of the available land along the stream if it could be properly stored. For the last 40 miles of its course the stream flows through the Mesa Verde in what is known as the Mancos Canyon, this lying in the Southern Ute Indian Reservation.[a] With plenty of water, considerable land might be irrigated for the benefit of the Indians in this canyon, but under existing conditions the stream is dry during a greater part of the summer season, and hence no irrigation is possible.

The station is located at the town of Mancos, a short distance below a wagon bridge near the center of the town. A number of ditches take their supply of water at points above the station and a number of others are located below. The channel is not gravel and is somewhat shifting, the bed changing so much in the year 1900 that no rating table was possible for that year.[b]

[a] Hayden's Report of 1875.

[b] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Ninth, p. 394; Tenth, p. 346. Publications U. S. Geological Survey: Twentieth Annual Report, Part IV, p. 404; Twenty-first, Part IV, p. 284; Water-Supply and Irrigation Papers No. 28, pp. 137, 142, 144; No. 38, p. 312; No. 39, p. 452, and No. 50, p. 384. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.

A. MANCOS CANYON IN MESA VERDE.

B. GRAND RIVER AT GRAND JUNCTION.

Estimated monthly discharge of Mancos River at Mancos.

[Altitude, 6,960 feet; drainage area, 117 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
March [a]			50	3,074	0.43	0.49
Apr. 10 to 30	375	123	261	15,531	2.23	2.49
May	270	144	206	12,667	1.76	2.03
June	291	144	213	12,674	1.82	2.03
July	333	2	104	6,395	.89	1.02
August	12	8	9	553	.08	.09
September	12	3	7	399	.06	.07
October [a]			5	307	.04	.04
November [a]			3	179	.03	.03
				51,779	.82	8.29
1899.						
March [a]			90	5,534	0.77	0.89
April	91	5	42	2,499	.36	.40
May	144	19	74	4,550	.63	.72
June	81	5	33	1,964	.28	.31
July	19	3	9	533	.08	.09
August	102	8	41	2,521	.35	.40
September	123	5	33	1,964	.28	.31
October	60	1	22	1,353	.19	.22
November [a]			5	298	.04	.04
				19,268	.30	3.07

[a] Approximate, no observations being made during these periods.

Discharge measurements made on Mancos River at Mancos.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1898.	*Feet.*	*Sec.-ft.*
Apr. 9	1.80	102
May 14	2.20	185
June 18	2.00	159
Oct. 18	.80	3

Discharge measurements made on Mancos River at Mancos.—Continued.

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Apr. 19	1.65	70
May 18	1.60	56
June 23	1.10	9
Sept. 22	.90	2
Nov. 24	1.00	3
1900.		
Mar. 23	1.05	4
May 7	1.80	82
June 26	1.70	16
Aug. 12	1.40	2

MISCELLANEOUS INVESTIGATIONS.

A number of miscellaneous gagings have been made at different points in this division, and are given in the table below. Most of these were taken during an investigation looking to the irrigation of lands belonging to the Southern Ute Indians. A full description of this investigation, with a statement of its results, may be found in the Twentieth Annual Report, Part IV, pages 408–434, and in the Twenty-first Annual Report, Part IV, page 286 et seq.

No seepage measurements have been made upon any of the streams of this region, but it is likely that the return from seepage is slight, as the stratification is such as to make any great returns improbable.

This region is also discussed in Hayden's Report for 1875.

Miscellaneous discharge measurements of San Juan River and tributaries.

[Hydrographer, Gerard H. Matthes.]

Date.	Stream.	Locality.	Discharge.
1898.			*Sec.-ft.*
Aug. 6	Los Pinos River	6 miles above Ignacio	246
Aug. 7	do	4 miles below Ignacio	196
Aug. 10	La Plata River	Hesperus	11
Aug. 18	San Juan River	Noland, Utah	609
Sept. 21	do	do	383
1899.			
Sept. 13	Mancos River	Head of canyon	3
Oct. 14[a]	do	In Mancos Canyon	100

[a] Estimated discharge for several hours following a heavy rain.

GRAND RIVER DIVISION.

IRRIGATION.

Grand River is the largest stream in Colorado, and drains the greatest territory. The main stream rises in Middle Park, in north-central Colorado, and drains the mountainous country on the west side of the Front Range and the south side of the Continental Divide in Middle Park. The Grand River and all of its tributaries flow through mountainous regions for considerable portions of their courses, and then generally enter a country the surface of which is usually undulating, but at times badly broken by deep canyons and ravines, the bottoms of these canyons being sometimes valleys of considerable extent, and again narrowing to mere threads. Along these canyons and valleys are often mesas of varied breadths. Upon most of the streams of this division but little irrigation has been practiced, except along the lowest valleys. There are, however, a few exceptions to this rule, the most notable ones being the Uncompahgre and Dolores rivers, which will be described more fully later. Upon some of the streams—as, for example, the San Miguel—a great deal of water is used for the purpose of developing power, the supply upon this stream being hardly adequate to the demands. Considerable power is developed upon other streams of this region also, the San Miguel, the Lake Fork of the Gunnison, and the Dolores being examples. Owing to the comparatively small amount of land that can be irrigated along the main stream, only a small proportion of the water in this division has been used, but a number of projects are under consideration with a view to diverting the water in great canals to the fertile mesas along the various streams, and in one case—namely, the Gunnison River—of taking water from that stream through the Divide for the purpose of irrigating lands in another valley—the Uncompahgre. Another great project now under consideration is that of taking the water of Grand River, by means of a very large canal, to the uplands of the western part of Colorado and the eastern part of Utah.

A number of the smaller tributaries of the Grand and its branches furnish a supply that is inadequate for the demands of irrigation, and storage is resorted to on a number of these streams, Surface Creek and Roan Creek being examples. The crops of this region vary with the altitude, only hay and grain being raised at the higher elevations, while fruits of an almost tropical nature may be raised where the Grand crosses the State line into Utah. A beet-sugar factory has been located at Grand Junction, and is successfully operated.

Irrigation division No. V, the Grand River division, covers the lands irrigated by the Grand and its tributaries. The relations existing between the different districts of this division are not so close as

is usually the case in the eastern half of the State. Except in a few cases the different districts are not interdependent, so that the water in one district is generally used without much reference to others, this being usually due to the fact that each stream flows into a river so large (the Grand) that its supply has not yet been exhausted. This will not long remain the case, however, and eventually the interdependence of the different districts will undoubtedly be almost as close as it is upon the South Platte.

There are 20 districts in this division, for the names and boundaries of which see Biennial Reports of the State Engineers of Colorado. For map see Pl. I of this paper, p. 20.

STREAM MEASUREMENTS.

The following stations have been maintained for a length of time sufficient to warrant publication of the records, measurements at other stations being given in the list of miscellaneous measurements for this division. These stations are at Glenwood Springs and Grand Junction, on Grand River; Iola and Grand Junction, on Gunnison River; Fort Crawford and Montrose, on Uncompahgre River; Dolores, on Dolores River; and Fall Creek, on San Miguel River.[a]

GRAND RIVER AT GLENWOOD SPRINGS.

This station was located May 12, 1899, at the request of the Denver and Rio Grande Railroad Company, at the railroad bridge one-quarter of a mile west of the depot and just above the mouth of Roaring Fork. A wire gage was used at this point, but records were kept up during the stage of high water only. On January 1, 1900, a new gage rod was located near the Glenwood Springs electric-light plant. Measurements are made from the wagon bridge across the river near the railroad station. The channel is good, being composed of gravel and of rock, and is not liable to great change, and the banks are high and not subject to overflow. Gagings are made from the bridge. The station is of importance, as it furnishes a good idea of the flow of Grand River available for the great irrigation projects contemplated below, measurements being made of Roaring Fork also whenever they are made at the Glenwood station.[b]

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[a] For further descriptions of this division see Hayden's Report of 1875. Also publications U. S. Geological Survey: Twelfth Annual Report, Part II, p. 290; Eighteenth, Part IV, p. 260; Nineteenth, Part IV, p. 360; Twentieth, Part IV, p. 373; Twenty-first, Part IV, p. 280; Bulletins No. 13, p. 47; No. 140, p. 186, and Water-Supply and Irrigation Papers. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell. For agricultural statistics see Biennial Reports of the State Engineers of Colorado.

[b] For more specific information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 350; Water-Supply and Irrigation Papers, U. S. Geological Survey, No. 37, p. 293; No. 50, p. 375, and Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 112.

Estimated monthly discharge of Grand River at Glenwood Springs.

[Altitude, 5,743 feet; drainage area, 5,838 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
January	970	810	890	54,724	0.15	0.17
February	935	810	883	49,039	.15	.16
March	1,460	902	1,187	72,896	.20	.23
April	3,940	1,120	1,818	108,178	.31	.35
May	22,895	3,245	11,963	735,577	2.05	2.36
June	22,390	7,622	14,817	881,673	2.54	2.83
July	7,270	1,515	3,121	191,903	.54	.62
August	1,460	935	1,134	69,727	.19	.22
September	870	755	800	47,603	.14	.16
October	755	755	755	46,423	.13	.15
November	935	728	805	47,901	.14	.16
December	840	570	681	41,873	.12	.14
The year	22,895	570	3,238	2,347,607	.56	7.55

Discharge measurements made on Grand River at Glenwood Springs.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
May 12	6.05	17,577
June 17	10.22	29,187
November 17	2.75	1,084
1900.		
March 19	3.80	1,140
July 8	5.40	3,764
August 23	3.60	1,086

GRAND RIVER AT GRAND JUNCTION.

This station was established October 18, 1894, and is located at the State wagon bridge across Grand River near the pump house of the city waterworks at Grand Junction, a short distance above the mouth of Gunnison River. The Grand at this point discharges through two channels, and a separate record of each is maintained, requiring separate discharge measurements. During the last four years by far the greater part of the water has run through the left channel; during the year 1900 there was a flow through the right channel for but a short time. Gage rod No. 1 is attached to the pier on the right bank of the river on the lower side; gage rod No. 2 consists of a wire and weight

fastened to the upper side of the bridge over the left channel. The channel is sandy and shifting, and the discharge must therefore be considered as approximate only. Owing to the small number of measurements made and to the changes in the channel it has been found impracticable to construct rating tables covering the entire period, so that the discharge for 1895, 1896, and 1900 are not given.[a]

Estimated total monthly discharge of Grand River at Grand Junction.

[Altitude, 4,594 feet; drainage area, 8,644 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
January			[b]1,000	[b]61,488	[b]0.12	[b]0.14
February			[b]1,050	[b]58,314	[b].12	[b].12
March			[b]1,100	[b]67,637	[b].13	[b].15
April	11,476	1,280	3,723	221,534	.43	.48
May	37,950	12,785	29,436	1,809,948	3.41	3.93
June	37,008	15,618	25,350	1,508,429	2.93	3.27
July	15,006	3,400	8,830	542,935	1.02	1.18
August	5,470	1,720	3,000	184,463	.35	.40
September	2,650	1,640	1,803	107,286	.21	.23
October	2,350	1,560	1,813	111,478	.21	.24
November	1,820	1,455	1,663	98,955	.19	.21
December			[b]1,550	[b]95,306	[b].18	[b].21
The year	37,950		6,693	4,867,773	.78	10.56
1898.						
January			[b]2,944	[b]181,020	[b].34	[b].39
February			[b]2,985	[b]165,777	[b].35	[b].36
March			[b]2,113	[b]129,924	[b].24	[b].28
April			[b]4,305	[b]256,165	[b].50	[b].56
May	12,642	4,633	7,130	438,406	.83	.94
June	17,262	8,279	13,702	815,326	1.59	1.77
July	7,611	1,725	4,445	273,312	.51	.59
August	1,725	949	1,127	69,297	.13	.15
September	1,143	561	907	53,970	.11	.12
October	1,143	561	915	56,261	.11	.13
November	1,337	755	1,072	63,788	.12	.14
December			1,011	62,164	.17	.20
The year	17,262		3,555	2,565,410	.42	5.63

[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 534; Ninth, p. 396; Tenth, p. 352. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 260; Nineteenth, Part IV, p. 400; Twentieth, Part IV, p. 389; Twenty-first, Part IV, p. 281; Bulletins, No. 131, p. 48; No. 140, p. 187; Water-Supply and Irrigation Papers No. 11, p. 67; No. 16, p. 137; No. 28, pp. 135, 142, and 144; No. 37, p. 294; No. 39, p. 451; No. 50, p. 376. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 121.

[b] Approximate.

Estimated total monthly discharge of Grand River at Grand Junction—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March			1,799	110,616	0.21	0.24
April			3,940	234,446	.46	.52
May			19,375	1,191,322	2.24	2.59
June			31,306	1,862,836	3.62	3.99
July			14,070	865,130	1.63	1.88
August			4,577	281,429	.53	.21
September			2,164	128,886	.25	.68

Discharge measurements made on Grand River at Grand Junction.

[Total discharge of both channels.]

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Oct. 18	A. P. Davis	2.10	1,585
1895.			
June 27	A. P. Davis	4.03	16,500
Oct. 1	do	.82	2,059
1896.			
Aug. 20	F. Cogswell	3.00	1,023
Sept. 20	do	3.90	1,694
Oct. 17	do	3.60	1,542
Nov. 10	C. C. Babb	3.35	1,497
1897.			
Apr. 20	C. C. Babb	5.60	5,176
May 19	W. B. Dougall	10.20	32,686
July 29	F. Cogswell	5.35	4,044
Sept. 29	do	4.05	2,062
Oct. 28	do	3.98	1,764
Nov. 23	C. C. Babb	3.90	1,423
1898.			
Apr. 25	A. L. Fellows	5.15	4,802
May 23	do	5.85	6,087
June 27	do	7.40	11,215
Aug. 27	do	3.35	1,237
Oct. 15	do	3.20	949

Discharge measurements made on Grand River at Grand Junction—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 15	A. L. Fellows	4.70	2,946
May 13	.....do	10.00	23,153
June 18	.....do	11.55	[a] 40,000
Sept. 19	.....do	4.20	1,989
Nov. 18	.....do	3.90	1,916
1900.			
Mar. 20	A. L. Fellows	4.15	1,762
July 7	.....do	5.80	6,177

[a] Approximate.

GUNNISON RIVER AT IOLA.

Gunnison River, the largest tributary of the Grand in Colorado, rises in the south central part of the State, in the Saguache Mountains and Cochetopa Hills, and flows in a westerly direction, emptying into the Grand near the western boundary of the State, a short distance from Grand Junction. Comparatively little of the water is yet used for irrigation, but a canal line has now been surveyed with a view to taking the water from Gunnison River and carrying it to the valley of the Uncompahgre for the purpose of irrigating the fertile plains there. It was for the purpose of determining the amount of water available for such a project that the Iola station was located, although several important tributaries enter the Gunnison between the point selected at Iola and the point where the canal would probably be taken out. The rod is placed at a wagon bridge which crosses the Gunnison about one-quarter of a mile above the railroad station of the Denver and Rio Grande Railroad at Iola, measurements having been made and records kept up during the year 1900 only. The channel is favorable to accuracy, being wide, and the bed being of gravel and bowlders and not particularly liable to change. The banks, although not high, are not subject to overflow.[a]

[a] For more specific information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 357; Water-Supply and Irrigation Paper, U. S. Geological Survey, No. 50, p. 378.

Estimated monthly discharge of Gunnison River at Iola.

[Drainage area, 2,298 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
April	1,258	551	773	45,997	0.34	0.38
May	4,388	1,157	2,875	176,777	1.25	1.44
June	4,265	1,460	2,726	162,208	1.19	1.33
July	1,359	350	727	44,701	.32	.37
August	450	350	360	22,136	.16	.18
September	350	250	260	15,471	.11	.12
October	250	250	250	15,372	.11	.13

Discharge measurements made on Gunnison River at Iola.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1900.	*Feet.*	*Sec.-ft.*
May 3	3.00	1,272
June 28	3.40	1,658
July 5	2.90	1,169
August 9	2.20	431
August 25	2.10	392

GUNNISON RIVER AT GRAND JUNCTION.

This station was located on July 3, 1895, at the wagon bridge across the Gunnison, about 1 mile from its junction with the Grand, and observations were made until December 21 of that year, after which none were made until 1897. The station was never satisfactory, high water from Grand River setting back into the mouth of the Gunnison, making the gage readings unreliable. The readings were discontinued, therefore, after the fall of 1899. The channel was uneven and somewhat shifting, some very large bowlders interfering very materially with the gagings. The banks are so high that there was no liability of overflow.[a]

[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 544; Ninth, p. 401; Tenth, p. 359. Also publications U. S. Geological Survey: Nineteenth Annual Report, Part IV, p. 404; Twentieth, Part IV, p. 390; Twenty-first, Part IV, p. 278; Bulletin No. 140, p. 189; Water-Supply and Irrigation Papers: No. 16, p. 141; No. 28, pp. 136, 142, and 144; No. 37, p. 297; No. 39, p. 451.

Estimated monthly discharge of Gunnison River at Grand Junction

[Altitude, 4,594 feet; drainage area, 7,935 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May	20,732	11,844	16,921	1,040,438	2.13	2.46
June	19,116	5,370	11,161	664,124	1.41	1.57
July	5,370	1,510	3,231	198,668	.41	.47
August	1,850	160	975	59,951	.12	.14
September	1,510	160	628	37,369	.09	.09
October	2,020	1,060	1,472	90,510	.19	.22
November	1,200	230	933	55,517	.12	.13
1898.						
May	8,996	3,965	5,318	326,993	.67	.77
June	11,361	4,158	8,850	526,610	1.12	1.25
July	3,965	1,076	2,543	156,364	.32	.37
August	968	578	689	42,365	.09	.10
September	578	399	479	28,502	.06	.07
October	672	399	533	32,773	.07	.08
November	672	314	497	29,573	.06	.07
1899.						
April	8,792	968	3,550	211,240	.45	.50
May	16,750	3,902	10,296	633,080	1.30	1.50
June	16,752	8,078	12,380	736,662	1.56	1.74
July	8,430	2,246	4,349	267,410	.55	.63
August	4,562	908	1,921	118,118	.24	.28
September	1,000	758	875	52,066	.11	.12

Discharge measurements made on Gunnison River at Grand Junction.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Oct. 17	A. P. Davis	1.25	748
1895.			
June 28	A. P. Davis	4.74	4,178
July 17	.....do	3.60	2,642
Oct. 1	.....do	1.95	781
1897.			
Apr. 20	C. C. Babb	5.20	5,975
May 20	W. B. Dougall	7.30	6,644
July 28	F. Cogswell	2.65	1,814
Sept. 28	.....do	2.40	1,246
Oct. 27	.....do	2.50	1,270
Nov. 23	C. C. Babb	2.30	828

Discharge measurements made on Gunnison River at Grand Junction.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Apr. 26	A. L. Fellows	4.65	5,932
May 23	.....do	4.50	4,647
June 28	.....do	4.62	5,274
Aug. 27	.....do	1.80	866
Oct. 15	.....do	1.50	578
1899.			
Apr. 15	A. L. Fellows	3.50	3,002
May 13	.....do	7.00	14,280
June 18	.....do	7.15	12,769
Sept. 19	.....do	2.20	1,061
Nov. 18	.....do	2.00	968
1900.			
Mar. 20	A. L. Fellows	2.50	1,477
July 7	.....do	2.90	2,121

UNCOMPAHGRE RIVER AT FORT CRAWFORD.

Uncompahgre River rises in Ouray County, in the high peaks of southwestern Colorado, and flows northwesterly, emptying into Gunnison River at Delta. The upper portion of its drainage basin is mountainous, but farther downstream the country is less broken and irrigation is possible along the valleys and adjacent mesas. Water is used to a certain extent for power purposes and in milling along the upper course of the stream. In the vicinity of Montrose a number of canals divert nearly all of the normal flow for irrigation purposes, and recourse must be had to storage or to the diversion of the waters of the Gunnison, already mentioned, for further irrigation in this district. The Fort Crawford station is located at a wagon bridge about one-quarter of a mile east of the railroad station at Fort Crawford, the post-office, known as Uncompahgre, being about 8 miles above, or south of, Montrose. The channel proved unsatisfactory, consisting of gravel bars which changed radically from time to time, rendering the rating tables untrustworthy. The discharge tables are therefore largely approximate.[a]

[a] For further details concerning this station, see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 19 and 41, and Part II, Pl. XIX; Eighth, p. 528; Ninth, p. 403; Tenth, p. 361. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 265; Nineteenth, Part IV, p. 402; Twentieth, Part IV, p. 391; Twenty-first, Part IV, p. 279; Bulletin No. 140, p. 188; Water-Supply and Irrigation Papers, No. 11, p. 69; No. 16, p. 139; No. 28, pp. 136, 142, and 144; No. 37, p. 296; No. 39, p. 451. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.

Discharge of Uncompahgre River at Fort Crawford.

[Altitude, 6,168 feet; drainage area, 497 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
April	.....	.....	386	327	263	325	19,339	0.65	0.72
May	.....	1,010	787	306	534	659	40,520	1.33	1.53
June	[b] 1,082	519	994	704	709	802	47,722	1.61	1.80
July	470	126	527	430	252	361	22,197	.73	.84
August	277	38	136	111	138	140	8,608	.28	.32
September	117	148	146	67	41	104	6,188	.21	.23
October	70	106	204	58	.....	109	6,702	.22	.25
November	82	86	127	54	.....	87	5,177	.18	.20
Mean	350	290	413	257	323	326	156,453	.66	5.89
Acre-feet for period recorded	110,346	123,050	194,424	124,440	117,303	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average eight months from April to November, inclusive, as calculated from the observations. Details may be found in the authorities cited.

[b] June 25 to 30.

Maximum and minimum discharge and average run-off of Uncompahgre River at Fort Crawford for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 6	55	June 28	1,535	0.78	0.70
1896	Aug. 15	10	May 27	3,375	.64	.58
1897	Sept. 1	55	June 15	1,467	.92	.83
1898	Aug. 3	15	June 24	985	.58	.52
1899	Sept. 10	4	June 15	1,163	.72	.65

[a] The run-off given is for that part of each year covered by the observations and for a thirty-day month, at the rate given as the mean second-feet per square mile for the period covered.

Discharge measurements made on Uncompahgre River at Fort Crawford.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 25	F. Cogswell	4.60	834
Aug. 26	do	3.25	218
Oct. 7	do	2.60	89
Nov. 18	do	2.55	92
1896.			
May 11	F. Cogswell	4.30	568
June 15	do	4.10	560
July 18	do	3.50	204
Aug. 21	do	2.90	31
Sept. 21	do	3.25	122
Oct. 18	do	3.10	95
1897.			
Apr. 18	F. Cogswell	3.90	487
May 10	do	4.55	884
June 21	do	5.05	1,081
July 19	do	4.50	473
Aug. 23	do	3.45	70
Sept. 20	do	3.85	153
Oct. 18	do	4.00	195
1898.			
Apr. 5	A. L. Fellows	3.55	91
May 9	do	3.92	203
June 15	do	5.18	720
Aug. 12	do	3.80	74

Discharge measurements made on Uncompahgre River at Fort Crawford—Cont'd.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Oct. 16	A. L. Fellows	3.75	56
1899.			
Apr. 16	A. L. Fellows	4.50	328
May 15	do	5.22	747
June 19	do	5.18	773
Sept. 21	do	3.65	69
Nov. 20	do	3.70	79

UNCOMPAHGRE RIVER AT MONTROSE.

This station was located at Montrose in the fall of 1899, no records being kept, however, until the spring of 1900. There is but little water at this point during the greater part of the year, as the canals above divert most of the flow. The station is located at a bridge crossing the river opposite the town of Montrose, about one-half of a mile from the station of the Denver and Rio Grande Railroad. The channel is favorable to accuracy, being of gravel and bowlders and not liable to change, and the banks are high and not subject to overflow. Records were kept up for a short time only, as there was but little water during the greater part of the irrigation season of 1900.[a]

Estimated monthly discharge of Uncompahgre River at Montrose.

[Altitude, 5,811 feet; drainage area, 565 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
April 8–30	71	18	50			
May	369	51	177	10,883	0.31	0.36
June	369	122	260	15,471	.46	.52
July 1–7	158	68	127			

[a] For further details concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 363. Also Water-Supply and Irrigation Paper, U. S. Geological Survey, No. 50, p. 379.

Discharge measurements made on Uncompahgre River at Montrose.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Sept. 20	0.40	15
Nov. 20	.45	15
1900.		
July 5	1.80	150
Aug. 10	.50	2

DOLORES RIVER AT DOLORES.

Dolores River is an important tributary of Grand River, rising in the La Plata and San Miguel Mountains, of which the highest peak, Mount Wilson, attains an elevation of over 14,000 feet. Its course is southwesterly for about 50 miles, where it turns and flows in an almost due northerly direction for nearly 100 miles, when it again turns west and enters Grand River, after crossing the Colorado-Utah line. The river flows for the greater part of its course through deep canyons, and comparatively little irrigation is practiced along the stream itself, excepting in the vicinity of Dolores, where for some 40 miles the valley widens out to from one-half of a mile to one mile, and a considerable area is cultivated. In the Paradox Valley again considerable land is cultivated, mostly, however, from small tributaries running into the main stream. At Rico a portion of the water is used for the development of power. By far the greater part of Dolores River, however, is used in the San Juan irrigation division, being diverted by means of a tunnel and a great cut into the Montezuma Valley. The head gates of the canals carrying this water are about 2 miles west of the present town of Dolores. The gaging station is located above these head gates and about one-half of a mile above the Rio Grande Southern Railroad station at Dolores. The channel is fairly favorable to accurate results, the bed being of small stones and gravel, and the banks being high and not liable to overflow.[a]

[a] For further details concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 516; Ninth, p. 405; Tenth, p. 364. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 261; Nineteenth, Part IV, p. 407; Twentieth, Part IV, pp. 312 and 408; Twenty-first, Part IV, p. 282; Bulletin No. 140, p. 191; Water-Supply and Irrigation Papers: No. 11, p. 68; No. 16, p. 143; No. 28, pp. 138, 142, and 144; No. 38, p. 305; No. 39, p. 451; No. 50, p. 380. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.

Discharge of Dolores River at Dolores.

[Altitude, 6,942 feet; drainage area, 524 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off.[a] Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b] 500	747	1,483	1,092	437	284	757	45,045	1.44	1.61
May	[b] 800	952	2,436	1,207	785	1,318	1,250	76,859	2.39	2.76
June	[b] 800	263	1,465	1,510	499	808	891	53,018	1.70	1.90
July	270	130	268	490	207	84	258	15,864	.49	.56
August	248	38	148	120	204	29	131	8,055	.25	.29
September	99	195	394	78	33	90	148	8,807	.28	.31
October	79	113	391	37	93	83	132	8,116	.25	.29
November	134	179	172	48	49	88	111	6,605	.21	.23
Mean	366	327	855	573	288	348	460	222,369	.88	7.95
Acre-feet for period recorded	177,144	158,356	413,824	277,428	139,324	168,360	.....	.....	.....	.....

[a] The run-off given in the horizontal lines is the total acre-feet for the eight months of each year. That given in the vertical columns is the acre-feet for normal months and the total for a normal eight months, the average monthly flow from each square mile, and the average for the eight months and the normal depth in inches for each normal month with the total depth for the normal eight months. Details may be found in the authorities cited.

[b] Estimated.

Maximum and minimum discharge and average run-off of Dolores River at Dolores for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 8	42	June 27	848	0.78	0.70
1896	Aug. 16	8	Apr. 26	1,578	.69	.62
1897	Aug. 31	76	Apr. 18	2,944	1.82	1.63
1898	Sept. 25	34	June 2	2,030	1.22	1.09
1899	Sept. 5	23	May 14	1,461	.61	.55
1900	Aug. 26	20	May 19	1,731	.73	.66

[a] The run-off given is the total acre-feet for the eight months of each year, the average second-feet per square mile, and the depth in inches for thirty days at the average rate.

Discharge measurements made on Dolores River at Dolores.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 22	F. Cogswell	3.50	756
Aug. 28	do	2.70	163
Oct. 9	do	2.50	89
Nov. 20	do	2.40	75
1896.			
May 13	F. Cogswell	3.50	553
May 14	do	3.50	586
June 17	do	3.00	179
July 21	do	2.80	124
Aug. 24	do	2.60	42
Sept. 23	do	4.80	1,550
Sept. 24	do	4.15	1,047
Oct. 1	do	2.75	76
1897.			
Apr. 21	F. Cogswell	5.10	2,133
May 12	do	5.15	2,216
June 23	do	4.20	1,089
July 21	do	3.00	273
Aug. 25	do	3.65	92
Sept. 22	do	3.32	404
Oct. 20	do	3.35	330
1898.			
Apr. 8	A. L. Fellows	3.15	325
May 12	do	4.30	1,163
June 17	do	4.80	1,870

Discharge measurements made on Dolores River at Dolores—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Aug. 16	G. H. Matthes	2.80	102
Sept. 11	do	2.70	72
Sept. 28	do	2.55	46
Oct. 21	A. L. Fellows	2.55	40
1899.			
Apr. 20	A. L. Fellows	3.60	613
May 17	do	4.15	963
June 27	do	3.30	307
Nov. 22	do	2.70	56
1900.			
Mar. 24	A. L. Fellows	2.90	145
May 5	do	3.90	767
June 27	do	3.25	320
Aug. 11	do	2.60	31

SAN MIGUEL RIVER AT FALL CREEK.

This stream, an important tributary of the Dolores, rises in San Miguel County and drains an area immediately west of the headwaters of Uncompahgre River. The stream and its tributaries run for the most part in a northeasterly direction, and it enters the Dolores in the western part of Montrose County. A comparatively small amount of water has thus far been used for irrigation, but plans are now being developed having reference to the use of the water on a considerable scale in the western part of San Miguel County. The station is located at a wagon bridge near the railway station at Fall Creek. The channel is fairly stable and the banks are not liable to overflow. The station was discontinued in the fall of 1899.[a]

[a] For further information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 522; Ninth, p. 407; Tenth, p. 368. Also publications U. S. Geological Survey: Annual Reports, Eighteenth, Part IV, p. 264; Nineteenth, Part IV, p. 406; Twentieth, Part IV, p. 335; Twenty-first, Part IV, p. 283; Bulletin No. 140, p. 193; Water-Supply and Irrigation Papers, No. 11, p. 68; No. 16, p. 142; No. 28, pp. 137, 142, and 144; No. 38, p. 306; No. 39, p. 451. Also report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 131.

A. GAGING STATION ON DOLORES RIVER AT DOLORES

B. GAGING STATION ON SAN MIGUEL RIVER AT FALL CREEK.

Discharge of San Miguel River at Full Creek.

[Altitude, 7,466 feet; drainage area, 327 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Mean run-off.		
							Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b] 200	281	213	[b] 200	134	206	12,258	0.63	0.70
May	[b] 500	770	[b] 500	296	416	496	30,498	1.52	1.75
June	[b] 556	349	774	813	538	606	36,060	1.85	2.06
July	341	157	375	380	238	298	18,323	.91	1.05
August	227	65	183	133	195	161	9,900	.49	.56
September	100	176	215	89	101	136	8,093	.42	.47
October	64	82	184	50	[b] 75	91	5,595	.28	.32
November	45	57	96	40	[b] 70	62	3,689	.19	.21
Mean	254	242	318	250	221	257	124,416	.79	7.12
Acre-feet for period recorded	122,936	117,128	153,912	121,000	106,764	.....	.....	.....	.....

[a] The run-off given is for the acre-feet for normal months with the total for a normal eight months as given, the average monthly flow per square mile with the average for the eight months, and the normal depth in inches for each month with the total depth for the normal eight months. Details may be found in the authorities cited.

[b] Estimated.

Maximum and minimum discharge and average run-off of San Miguel River at Fall Creek for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Dec. 24	6	June 29	587	0.87	0.78
1896	Nov. 7	22	May 27	2,404	.82	.74
1897	Apr. 4	52	June 16	997	1.08	.97
1898	Nov. 21	22	June 23	1,335	.84	.76
1899	Apr. 2	25	June 11	1,000	.75	.68

[a] The run-off is for the average of second-feet per square mile, and the depth in inches for thirty days at the average rate.

Discharge measurements made on San Miguel River at Fall Creek.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 24	F. Cogswell	4.00	512
Aug. 27	do	3.20	205
Oct. 8	do	2.65	81
1896.			
May 12	F. Cogswell	3.75	360
June 16	do	3.45	290
July 20	do	3.15	175
Aug. 23	do	2.60	62
Sept. 22	do	2.75	85
Oct. 20	do	2.60	63
1897.			
Apr. 20	F. Cogswell	3.40	304
May 11	do	4.05	572
June 22	do	4.45	811
July 20	do	3.45	336
Aug. 24	do	2.85	145
Sept. 21	do	3.30	248
Oct. 19	do	3.05	197
1898.			
Apr. 7	A. L. Fellows	2.50	66
May 11	do	3.30	270
June 16	do	4.40	841
Aug. 13	do	2.80	133
Oct. 17	do	2.30	30

Discharge measurements made on San Miguel River at Fall Creek—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 18	A. L. Fellows	2.85	164
May 16	.....do	3.70	562
June 21	.....do	3.60	449
Nov. 21	.....do	2.35	52

MISCELLANEOUS MEASUREMENTS.

But few measurements are on record for this division, the danger of shortage having been only recently felt. Many measurements have undoubtedly been made, mostly for the purpose of ascertaining the flow with reference to development of power, but these are not, as a rule, available. Further investigations are needed in this division, as the supply of water will become of great moment before many years have elapsed. The following are, however, on record. Other measurements may also be found on page 108 et seq. of the Ninth Biennial Report of the State Engineer:

Stream measurements in Grand River division.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
1895.				*Sec.-ft.*
Oct. 22	D. R. Crosby	Grand River	Palisade	2,767
1899.				
Apr. 19	A. L. Fellows	Dolores	Rico	168
May 16	.....do	Fall Creek	Falls Creek	62
June 17	.....do	Roaring Fork	Glenwood	11,258
June 21	.....do	Fall Creek	Fall Creek	45
Sept. 22	.....do	Dolores	Rico	23
Nov. 17	.....do	Roaring Fork	Glenwood	457
Nov. 22	.....do	Dolores	Rico	16
1900.				
July 8	A. L. Fellows	Roaring Fork	Glenwood	1,570
Aug. 23	.....do	.....do	.....do	423

GREEN RIVER DIVISION.

DRAINAGE AND IRRIGATION.

Green River and its tributaries drain the northwestern corner of Colorado. The Green itself traverses Colorado for only a very short distance, and during its course it runs through a deep canyon, so that but little irrigation is practiced along its borders, this being on the bottom lands. It is possible, however, that a tract of land of considerable size may eventually be irrigated from this stream, in the extreme northwestern corner of the State. The principal tributaries of the Green in Colorado are Yampa and White rivers. These drain areas of considerable size and importance, in which there are vast tracts of irrigable land that will undoubtedly be eventually cultivated so far as the water supply will permit. These streams resemble the tributaries of Grand River in general, excepting that they traverse a country that is more open and rolling. Not much irrigation is now practiced except along lands immediately adjoining the stream, but a number of plans have been projected for taking the water on to the uplands, which will no doubt be eventually carried out. No permanent stations have been maintained anywhere in this division, so that all measurements on record are compiled in the following list of miscellaneous gagings. Problems relating to the use of water are, however, becoming of great moment in this part of the State, and it is important that stations should be established at as early a date as possible, at least upon the main streams.

The Green River irrigation division, as a political subdivision, comprises all lands in Colorado drained by Green River and its tributaries. The water districts of which it is composed are Nos. 43, 44, 54, 55, 56, 57, and 58. No. 43 consists of the lands irrigated by ditches taken from White River and its tributaries; No. 44 of lands irrigated by water taken from that portion of Yampa River above the mouth of Little Snake River and below the mouth of Fortification Creek, and from the tributaries to that portion of Yampa River; No. 54 of all lands lying in the State of Colorado irrigated by water taken from that portion of Little Snake River and its tributaries above the most westerly intersection of said river with the Colorado State line; No. 55 of all lands irrigated by water from the Yampa or Little Snake rivers and their tributaries below districts Nos. 44 and 55; No. 56 of Green River and tributaries in Colorado, except Yampa River; No. 57 of Yampa River and tributaries between the mouth of Fortification Creek and Elk River; and No. 58 of Yampa River and tributaries above No. 57. But little attention has thus far been paid to the priorities of water rights in these districts.[a]

[a] For further data concerning this division, see publications U. S. Geological Survey: Ninth Annual Report, p. 677; Eighteenth, Part IV, p. 268; Nineteenth, Part IV, p. 394; Twentieth, Part IV, p. 380; Eleventh Census Irrigation Report by F. H. Newell and Bulletin No. 140, p. 200. Also Biennial Reports of the State Engineer of Colorado, Ninth, p. 409; and all biennial reports for commissioners' reports.

A. STEAMBOAT SPRINGS.

B. YAMPA RIVER VALLEY NEAR HAYDEN.

MISCELLANEOUS GAGINGS.

In the following table are given the results of gagings made in May, 1895, and September, 1898, on certain specified streams in the Green River irrigation division:

Miscellaneous gagings made in the Green River irrigation division.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
1895.				*Sec.-ft.*
May 16	H. A. Sumner	White River	White River	3,047
1898.				
Sept. 14	A. L. Fellows	White River	Meeker	300
Sept. 15	do	Williams River	Hamilton	25
Sept. 17	do	Yampa River	3 miles below Hayden	111
Do.	do	Elk River	Trull	63
Sept. 18	do	Yampa River	Steamboat Springs	65
Sept. 19	do	Snake River	Honnold	17
Sept. 20	do	Slater Fork	Slater	9
Sept. 21	do	Snake River	Dixon, Wyo	19
Sept. 22	do	Yampa River	Below Maybell	99
Sept. 24	do	Green River	Ladore	552
Sept. 26	do	Yampa River	Craig	79

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

REPORT

OF

PROGRESS OF STREAM MEASUREMENTS

FOR

THE CALENDAR YEAR 1901

BY

F. H. NEWELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 30, 1902.

SIR: I have the honor to transmit herewith a manuscript for a paper descriptive of the results of hydrographic surveys made during the calendar year 1901. This paper may be considered as being the third and last part of the Annual Report of the Division of Hydrography for 1901, Parts I and II having been printed as Water-Supply Papers Nos. 65 and 66, giving the gage heights and measurements at various river stations maintained during 1901. This form of publication has resulted from the limitations formerly imposed by law and through the operation of recent changes which have been made. At the time that Paper No. 65 was put in type it was proposed to print the manuscript herewith presented as Part IV of the Twenty-third Annual Report. By act of May, 1902, the report of the Director was limited to one volume, and the restriction of Water-Supply Papers to 100 pages was removed. As a result, the material which otherwise would have appeared as one of the volumes of the Director's report is now presented for publication in the Water-Supply and Irrigation series.

This paper presents briefly the results of computations of river flow, the data for them having been presented in Water-Supply Papers Nos. 65 and 66. This separation of the original observations of gage height and river measurement was brought about by the fact that since 1895 it has been found desirable to print as soon as possible after the conclusion of each calendar year the tables of gage heights and related facts, reserving for the annual report of the Director the conclusions resulting from computations and the diagrams of discharge, together with maps and other illustrations. This plan is carried out for 1901, with the exception of the modification noted in the first paragraph. It is proposed, however, in the future to combine and publish together the original observations and results for each locality.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

HON. CHARLES D. WALCOTT,
Director United States Geological Survey.

PROGRESS REPORT OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1901.

By F. H. NEWELL.

GENERAL STATEMENT.

The determinations of the water supply of various parts of the United States have been continued during the year 1901 by the Division of Hydrography in a manner similar to that of previous years, slight modifications and improvements having been introduced in methods and operations. The work consists in measuring the streams and estimating the water supply, both above and under ground. To give full facts concerning the water supply it is necessary not merely to ascertain the quantity, but also in many cases the quality, and especially the possibilities of water storage or conservation. Water can not be considered as a resource unless it can be had when needed, and therefore the determination of the practicability of holding the floods until time of drought underlies any statement of water supply. In a similar way when considering underground waters it is not enough to know that there is water beneath the surface, but the facts must be ascertained as to the depth to the water, the rate of movement, if any, and the possibility of bringing the water to the surface at reasonable cost.

The principal operation of the hydrographic surveys, as at present conducted, is that of measuring the waters flowing upon the surface, obtaining their fluctuations in quantity, and sometimes in quality, from month to month and from year to year. The points at which the principal systematic measurements were made during the year 1901 are shown in figs. 1 and 2 by the heavy dots upon the branching lines of river systems.

HISTORICAL REVIEW.

Under the operation of various resolutions of Congress and appropriation acts, systematic hydrographic measurements have been carried on by the Geological Survey since 1888, papers Nos. 65, 66, and 75, taken together, constituting what may be termed the annual report

for the fourteenth year of the water supply and irrigation survey. The hydrographic data obtained during these years are scattered through a number of publications. In order to facilitate reference to these,

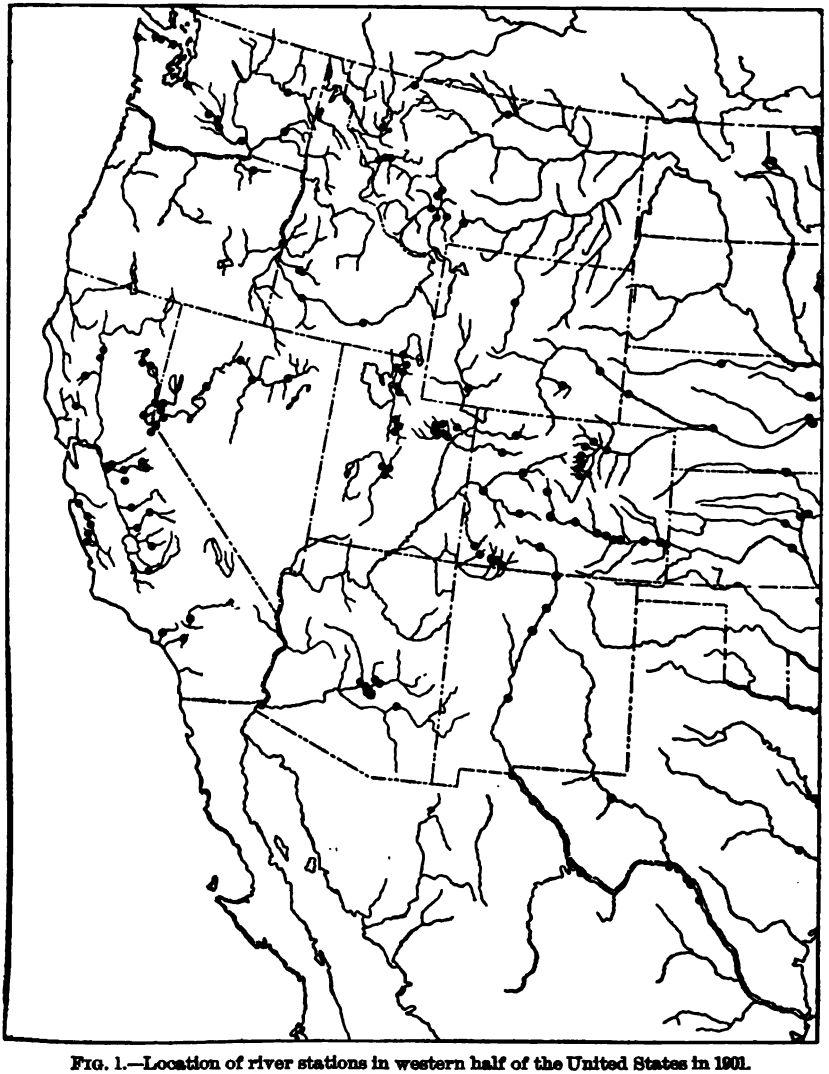


FIG. 1.—Location of river stations in western half of the United States in 1901.

the following brief review is given of the progress of the investigation, showing in chronologic order the development of the work:

1888, first year.—The Irrigation Survey was organized in accordance with the provisions of the act of October 2, 1888. The results of the first year's work are given in the Tenth Annual Report of the Geological Survey, Part II, Irrigation. This volume is devoted mainly to the details of organization and of the plans adopted and partly executed.

1889, second year.—The results of the operations outlined in the report just named are given in the Eleventh Annual Report, Part II, Irrigation. This contains a discussion of the hydrography and of the

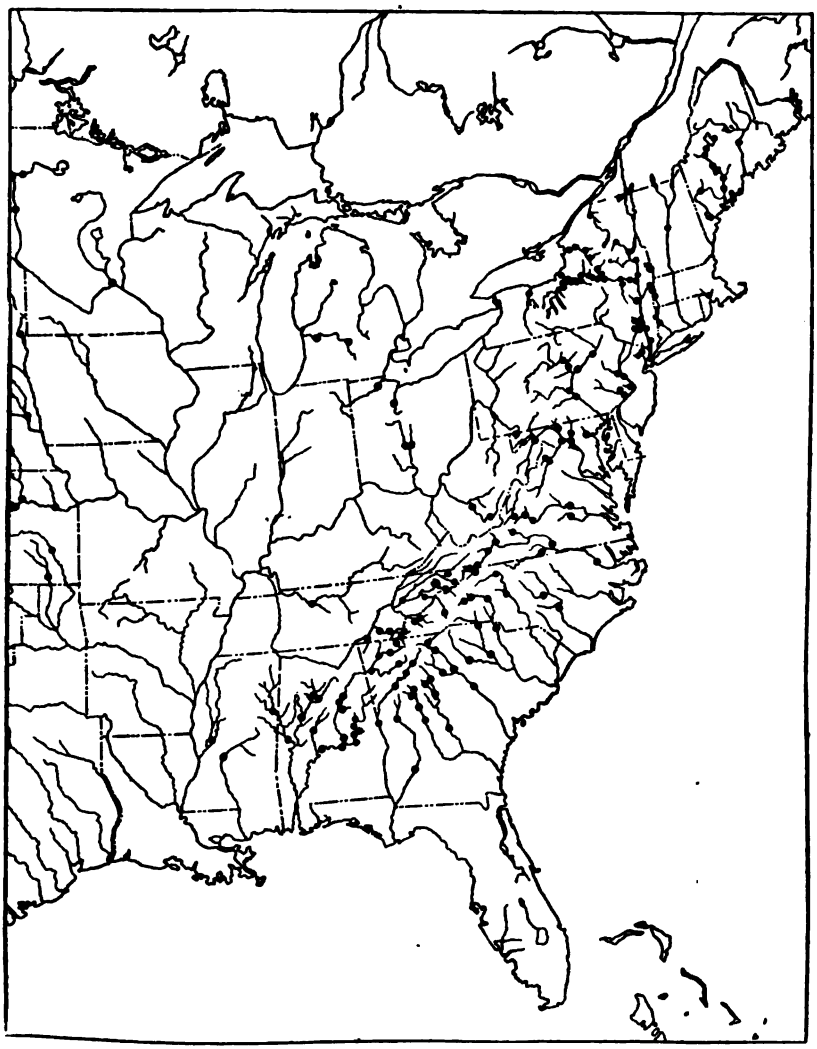


FIG. 2.—Location of river stations in eastern half of United States in 1901.

engineering surveys for canals and reservoirs, the statement of the Director of the Geological Survey to the House Committee on Irrigation, a report upon the topographic surveys relating to reclamation work, and a list of irrigation literature.

1890, third year.—The results of operations are given in the Twelfth Annual Report, Part II, Irrigation. This contains a statement of the location and survey of reservoir sites, by A. H. Thompson; a paper

on the hydrography of the arid region, by F. H. Newell, and a discussion of irrigation in India, by Herbert M. Wilson.

1891, fourth year.—The discussion of results obtained is continued in the Thirteenth Annual Report, Part III, Irrigation. This consists of a paper upon water supply for irrigation, by F. H. Newell; two papers by Herbert M. Wilson, the first upon American irrigation engineering and the second upon the engineering results of the Irrigation Survey, and a report by A. H. Thompson upon the location and survey of reservoir sites during the fiscal year.

1892, fifth year.—The Fourteenth Annual Report, Part II, contains a paper entitled "The results of stream measurements," by F. H. Newell. With this are two others bearing upon hydrography, the first, entitled "Potable waters of eastern United States," by W J McGee; the second, "Natural mineral waters of the United States," by A. C. Peale.

1893, sixth year.—The results of field work during this year are shown in Bulletin No. 131.

1894, seventh year.—The operations of this year are also shown in Bulletin No. 131. The Sixteenth Annual Report, Part II, contains a paper entitled "The public lands and their water supply," by F. H. Newell. This gives in condensed form the results of hydrographic work in preceding years. There is also in the same volume a report on the "Water resources of a portion of the great plains," by Robert Hay.

1895, eighth year.—Bulletin No. 140, entitled Report of Progress of the Division of Hydrography, gives the results of field work during the greater part of this year. The Seventeenth Annual Report contains a paper by G. K. Gilbert on the "Underground waters of the Arkansas Valley in eastern Colorado;" one by Frank Leverett on the "Water resources of Illinois," and another, by N. H. Darton, on "Artesian waters of a portion of the Dakotas."

1896, ninth year.—For this year was begun the method of double publication, the gage heights being published in Water-Supply Paper No. 11, and the results of computations, the illustrations, etc., being given in the Eighteenth Annual Report, Part IV.

1897, tenth year.—The gage heights are given in Water-Supply and Irrigation Papers Nos. 15 and 16 and the detailed descriptions in the Nineteenth Annual Report, Part IV.

1898, eleventh year.—The operations at river stations are given in Water-Supply Papers Nos. 27 and 28, while the results are shown in the Twentieth Annual Report, Part IV.

1899, twelfth year.—The operations at river stations are contained in Water-Supply Papers Nos. 35 to 39, inclusive, and the discussion of results in the Twenty-first Annual Report, Part IV.

1900, thirteenth year.—The operations at river stations are given in Water-Supply Papers Nos. 47 to 52, inclusive, while the final tables

and illustrations are shown in the Twenty-second Annual Report, Part IV.

1901, fourteenth year.—The operations at river stations are given in Water-Supply Papers Nos. 65 and 66, while the conclusions, with illustrations, are shown in Water-Supply Paper No. 75 instead of Part IV of the Twenty-third Annual Report, this latter report being confined to one volume.

The hydrographic surveys have been from necessity confined to the United States proper, but urgent appeals have been received for similar work in southern Alaska, the Hawaiian Islands, and other outlying possessions. The rivers of southern Alaska have considerable value as sources of water power and will probably be utilized in the future in connection with mining operations and the reduction of ores. The vast extent of Alaska and the public lands, some of which have great value from their mineral resources, are little realized, and it is only when the area of Alaska is compared with that of the States of the Union that comprehension can be had of the extent of land surface and area over which mineral and water resources are distributed.

ACKNOWLEDGMENTS.

Most of the measurements presented in Papers 65, 66, and in this paper have been obtained through local hydrographers, a comparatively small portion of the work having been conducted directly from the office of the Geological Survey at Washington. Acknowledgment is due to each of these persons, and thanks are extended to other persons and to corporations who have assisted the local hydrographers or have cooperated in any way, either by furnishing records of the height of water or by assisting in transportation. The following list, arranged alphabetically by States, gives the names of the resident hydrographers:

California: J. B. Lippincott, civil engineer, Los Angeles.

Colorado: A. L. Fellows, civil engineer, Denver.

Georgia and Alabama: Prof. B. M. Hall, civil engineer, Atlanta; Prof. W. S. Yeates, State geologist, Atlanta; and Prof. Eugene A. Smith, State geologist, Tuscaloosa.

Idaho: N. S. Dils, civil engineer, Caldwell.

Kansas: W. G. Russell, Russell.

Maryland: Prof. W. B. Clark, State geologist, Baltimore.

Montana: Prof. Samuel Fortier and J. S. Baker, Bozeman.

Nebraska: Prof. O. V. P. Stout, State University, Lincoln, assisted by Adna Dobson and Glenn E. Smith.

Nevada: L. H. Taylor, civil engineer, Carson City.

New Mexico: P. E. Harroun, civil engineer, Albuquerque.

North and South Carolina: Prof. J. A. Holmes, State geologist, Chapel Hill, N. C., assisted by E. W. Myers.

Texas: Prof. Thomas U. Taylor, State University.

Utah: Prof. George L. Swendsen, Logan.

Virginia and West Virginia: Prof. D. C. Humphreys, Washington and Lee University, Lexington, Va.

Washington: Sydney Arnold, civil engineer, North Yakima.

Wyoming: A. J. Parshall, civil engineer, Cheyenne.

In Colorado the State engineering department (Mr. A. J. McCune in charge) has cooperated, and valuable assistance has been rendered by the Denver and Rio Grande, the Union Pacific, the Colorado and Southern, the Rio Grande Southern, the Atchison, Topeka and Santa Fe, and the Burlington and Missouri River railroads. Special thanks are also due to the officers and employees of The Great Plains Water Company, one of whose engineers, Mr. C. W. Beach, has made many measurements on the Arkansas; to the Amity Land and Canal Company and its chief engineer, Mr. Thomas Berry; to the Buffalo Canal Company; to Mr. C. L. Harrison, chief engineer of the Denver Union Water Company; to Messrs. S. M. Matlock, T. J. Burrows, J. M. Wolaver, L. H. Dickson, Thomas Kneale, W. E. Obert, and other water commissioners in various parts of the State, and to many others who have furnished valuable information.

In California assistance in transportation has been rendered by Mr. William Hood, chief engineer of the Southern Pacific Company, who has also procured the assistance of bridge watchmen in observing the height of water in the rivers. Mr. Walter James, chief engineer of the Kern County Land Company, has supplied records of Kern River, and Mr. A. K. Warren, assistant engineer, has also furnished information. Mr. H. F. Parkinson, superintendent of canals taking water from San Gabriel River above Azusa, has furnished records of that stream; Mr. T. F. Keefe, secretary of the Fontana Development Comnany, has furnished records of Lytle Creek; and Mr. K. Sanborn, engineer of the Riverside Water Company, rendered valuable assistance in making low-water measurements. Mr. W. G. Nevin, general manager of the Southern California Railroad, has furnished transportation over the Santa Fe lines in California. The Los Angeles City Water Company has maintained gagings of Los Angeles River, which, through the courtesy of Mr. William Mulholland, city engineer, have been furnished to the Survey without charge. Mr. H. N. Savage, chief engineer, of the San Diego Land and Town Company, has contributed information concerning Sweetwater River.

In Georgia, Alabama, Florida, Tennessee, and Mississippi Prof. B. M. Hall and Mr. Max Hall, resident hydrographers, have been assisted in their work by the following persons and corporations: Prof. W. S. Yeates, State geologist of Georgia, has paid the observers at Madison, Tallulah Falls, Juliette, Almon, and Blueridge, and for a portion of the year the observers at Carters, Canton, and Woodbury. Dr. Eugene A. Smith, State geologist of Alabama, has paid the observers at Riverside, Cordova, Milstead, Susanna, Sturdivant, Dadeville, Alex-

ander, and Nottingham. The city of Augusta maintains the station at Augusta, Ga. The officials of the United States Weather Bureau have shown a great interest in the work and have rendered valuable assistance, particularly Messrs. J. B. Marbury, D. Fisher, F. P. Chaffee, L. M. Pindell, W. M. Dudley, and T. S. Collins. They have maintained stations at Calhoun Falls, S. C.; at Carlton, Dublin, Albany, West Point, and Oakdale, in Georgia; at Montgomery and Selma, in Alabama, and at Chattanooga and Knoxville, in Tennessee; and for a part of the year stations at Woodbury, Canton, Resaca, and Rome, in Georgia, and at Charleston, Tenn. Acknowledgments are also due to Messrs. R. C. McCalla, D. M. Andrews, and G. T. Nelles, United States assistant engineers, for cooperation in the work by sending records of stations at Tuscaloosa, Ala., and Lincoln, Ala., and furnishing valuable data concerning the Coosa, Cahaba, Warrior, Tennessee, and other rivers. Also to Prof. C. M. Strahan, of Georgia University; to Prof. C. S. Wilkins, of Alabama University; to Prof. W. M. Fulton, of Tennessee University; to Mr. H. S. Weems, of Carters, Ga.; and to Mr. W. M. Towers, of Rome, Ga. Transportation has been furnished through the kindness of Mr. J. S. B. Thompson, general agent of the Southern Railway; Mr. E. St. John, vice-president and general manager of the Seaboard Air Line; Mr. Thomas K. Scott, general manager of the Georgia Railroad; Mr. John M. Egan, president of the Central of Georgia Railway; Mr. James T. Wright, president and general manager of the Macon, Dublin and Savannah Railroad; Mr. John B. Newton, general manager of the Atlanta, Knoxville and Northern Railway; Mr. W. B. Denham, general superintendent of the Plant System; Mr. C. A. Wickersham, president and general manager of the Atlanta and West Point Railway and the Western Railway of Alabama; Mr. Hunter McDonald, chief engineer of the Nashville, Chattanooga and St. Louis Railway; Mr. Y. van den Berg, vice-president of the Louisville and Nashville Railroad, and Mr. J. T. Harahan, second vice-president of the Illinois Central Railroad.

Thanks are due to the Norfolk and Western Railway for an annual pass over all lines in Virginia and West Virginia, issued to Prof. D. C. Humphreys, and to the Chesapeake and Ohio Railway for a similar courtesy during the months of July, August, and September. Thanks are also due to Mr. Charles S. Churchill, of Roanoke, Va., for suggestions and assistance.

In Idaho the State engineer, Mr. D. W. Ross, has heartily cooperated. Transportation has also been furnished to Mr. N. S. Dils and others in the employ of the Survey, through the kindness of Mr. D. E. Burley, general passenger and ticket agent of the Oregon Short Line.

In connection with the work in Kansas the Survey is under obligations to the Missouri, Kansas and Texas Railway, the Union Pacific

Railway, and the Santa Fe Railroad for transportation furnished to Mr. W. G. Russell, resident hydrographer.

In Montana assistance has been rendered by the Great Northern Railroad, by the Bitterroot Stock Farm, of Hamilton; by Prof. M. J. Elrod, of Missoula University; by J. D. O'Donnell, of Billings, and by Mr. J. L. Rhead, superintendent of the Big Ditch at Laurel, Mont.

In Nebraska the resident hydrographer, Prof. O. V. P. Stout, has had the benefit of the continued cooperation of various public and private organizations. Special acknowledgments are due to the agricultural experiment station and the State board of irrigation for the service of hydrographers, to the State board of agriculture for the preparation and publication of valuable data, and to the following railway officials, without whose assistance the amount of work accomplished would have been greatly lessened: Mr. G. W. Holdredge, general manager of the Burlington lines west of Missouri River; Mr. George F. Bidwell, general manager of the Fremont, Elkhorn and Missouri Valley Railroad, and Mr. E. L. Lomax, general passenger agent of the Union Pacific Railroad; also to Prof. A. B. Crane, of the South Dakota Agricultural College, for measurements of Big Sioux River.

In Nevada officials of the Southern Pacific Railroad Company, of the Nevada-California-Oregon Railway Company, and of the Lake Tahoe Railway and Transportation Company have furnished transportation to Mr. L. H. Taylor, enabling him to greatly extend his field work.

In Wyoming transportation has been furnished to Mr. A. J. Parshall by Mr. E. Dickinson, general manager of the Union Pacific Railroad; by Mr. G. W. Holdredge, general manager of the Burlington and Missouri Railroad; by Mr. George F. Bidwell, general manager of the Fremont, Elkhorn and Missouri Valley Railroad, and by Mr. Frank Trumbull, general manager of the Colorado and Southern Railway, thus greatly increasing the amount of work accomplished.

In Washington the work has been facilitated by transportation furnished to Mr. Sydney Arnold by Mr. Thomas Cooper, general manager of the Northern Pacific Railway.

NORTHERN ATLANTIC COAST DRAINAGE.

Under this heading have been included data pertaining to the rivers entering the Atlantic Ocean from Maine to Virginia, inclusive, an arbitrary line being drawn between James River and Roanoke River, the latter stream being included in the southern Atlantic coast drainage.

In order to systematize the work of stream gaging in Maine, permanent gaging stations were established during the season of 1901 by the Geological Survey on a number of rivers in the State of Maine that are of peculiar interest on account of their water powers. Practically all of the data heretofore published on the Maine streams have been

furnished through the courtesy of local engineers and milling companies from their own records. As the data obtained at the newly established stations are as yet too incomplete to warrant computation of the discharge at these points, no results of measurements are given for 1901. As in preceding years, records of daily discharge have been kept by the Forest Paper Company at Yarmouthville, Me., on Cobbosseecontee River, at the reservoir dam, near Augusta; by the Rumford Falls Power Company, at Rumford Falls, on Androscoggin River, and by Mr. Hiram F. Mills, of Lowell, Mass., on Presumpscot River, at the outlet of Sebago Lake. The results of these measurements for 1901 are given in the following pages, where are also given results of observations made on Penobscot River at Sunk Haze Rips, near Costigan, Me., for the years 1899 and 1900. A full description of the Maine rivers and their drainage basins, together with tabulated statements of their flow, has been published in Water Supply Paper No. 69, entitled "Water Powers of the State of Maine," by H. A. Pressey.

Measurements of streams in New York State have been made as in previous years with the cooperation of the State engineer and surveyor, Edward A. Bond, and the deputy State engineer and surveyor, William Pierson Judson, under the immediate supervision of Robert E. Horton. The majority of these stations were primarily established in connection with a study for the water supply of the New York State canals and the Upper Hudson storage survey. The gage records for 1901 and tabulated results by months for the entire period of observation for each station have been published in Water-Supply Paper No. 65. During 1901 additional stations were established through cooperation of the department of water supply of New York, George W. Birdsall, chief engineer, for studying the possible sources of future municipal water supply for Greater New York. These stations are located as follows: Dover Plains, on Tenmile River; South Cairo, on Catskill Creek; Kingston, on Esopus Creek; New Paltz, on Wallkill River; Rosendale, on Rondout Creek; Glenham, on Fishkill Creek; and Gaylordsville, on Housatonic River. With the exception of the last-named station, which is in Connecticut, the stations are all within the State of New York. Descriptions of these stations, together with records of gage heights and results of measurements of the streams made in June, 1901, by H. A. Pressey and R. E. Horton, are published in Water-Supply Paper No. 65, pages 59–90.

Following is a complete list of the gaging stations maintained during the past season in the State of New York:

Raquette River at Hannawa Falls.
Black River at Watertown.
Black River at Felts Mills.
Beaver River at Tisses Bridge.
Indian River at Indian Lake Dam.
Schroon River at Warrensburg.
Moose River at Moose River.
Salmon River at Pulaski.
Oswego River at Fulton (High Dam, Minetto Station).
Seneca River at Baldwinsville.
Skaneateles Outlet at Willow Glen and Jordan.
Genesee River at Rochester.

Oneida River at Brewerton.
West Branch Fish Creek at McConnellsville.
Chittenango Creek at Bridgeport.
Chittenango Creek at Chittenango.
Oneida Creek at Kenwood.
Mohawk River at Ridge Mills.
West Canada Creek at Twin Rock Bridge.
Oriskany Creek at Woods road bridge.
Saquoit Creek at New York Mills.
Mohawk River at Utica.
West Canada Creek at Middleville.
Mohawk River at Little Falls.
East Canada Creek at Dolgeville.
Cayadutta Creek at Johnstown.
Hudson River at Fort Edward.
Schoharie Creek at Fort Hunter.
Schoharie Creek at Millpoint Aqueduct.
Schoharie Creek at Schoharie Falls.
Mohawk River at Schenectady.
Mohawk River at Rexford Flats.
Hudson River at Mechanicville.
Mohawk River at Dunsbach Ferry.
Normanskill Creek at French's Mill.
Kinderhook Creek at East Nassau and Wilson's dam.
Catskill Creek at South Cairo.
Esopus Creek at Kingston.
Rondout Creek at Rosendale.
Wallkill River at New Paltz.
Fishkill Creek at Glenham.
Rondout Creek at Honk Falls.
Croton River at old Croton dam.
Chenango River at Binghamton.
Susquehanna River at Binghamton.
Tenmile River at Dover Plains.
Richelieu River at Fort Montgomery.

NEW ENGLAND STREAMS.

Estimated monthly discharge of Penobscot River near Costigan, Me.

[Drainage area, 7,450 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
October	5,100	2,330	2,764	0.31	0.36
November	14,000	3,300	7,170	.96	1.07
December	11,500	4,800	9,014	1.21	1.40
1900.					
January	35,400	9,500	14,876	2.00	2.31
February	52,400	26,200	37,262	5.00	5.21
March	62,700	29,200	43,828	5.88	6.77
April	75,100	36,600	52,407	7.03	7.84
May	74,700	44,200	56,632	7.60	8.76
June	41,600	7,800	20,435	2.74	3.06
July	21,400	11,300	13,769	1.85	2.13
August	14,100	4,850	10,722	1.44	1.66
September 1-21			4,507	.60	.47

NOTE.—Daily discharge for 1899 and 1900 is given in Water-Supply Paper No. 65, pages 14 and 15.

EDWARD WARE'S MILL AT WINSLOW, ME., DURING SPRING FLOOD ON KENNEBEC RIVER.

Estimated monthly discharge of Cobbosseecontee River near Augusta, Me.

[Drainage area, 230 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	250	220	231	1.00	1.15
February	220	120	173	.75	.78
March	1,404	120	344	1.50	1.73
April	3,205	260	2,046	8.90	9.93
May	483	26	290	1.26	1.45
June	510	280	306	1.33	1.48
July	280	280	280	1.22	1.41
August	280	280	280	1.22	1.41
September	280	270	274	1.19	1.33
October	270	250	252	1.10	1.27
November	250	220	246	1.07	1.19
December	2,700	220	526	2.29	2.64
The year	3,205	26	437	1.90	25.77

NOTE.—Daily discharge for 1891 is given in Water-Supply Paper No. 65, page 20.

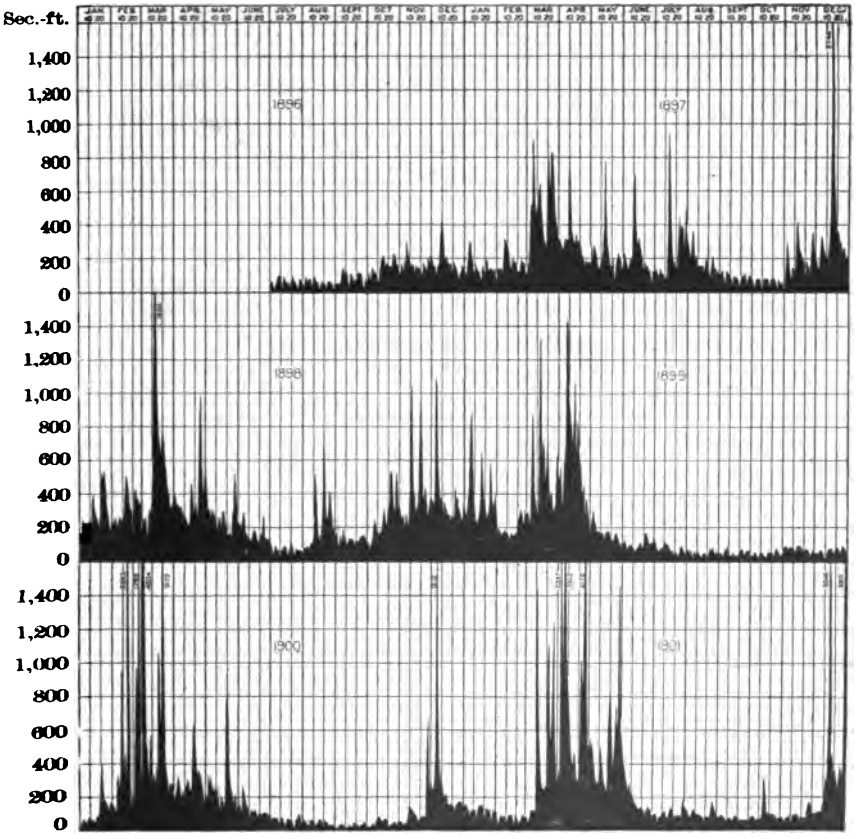


FIG. 8.—Discharge of Nashua River at Clinton, Mass., 1896-1901.

Estimated monthly discharge of Androscoggin River at Rumford Falls, Me.

[Drainage area, 2,820 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,082	1,692	1,895	0.82	0.95
February	2,496	1,563	1,832	.79	.82
March	4,445	1,873	2,463	1.06	1.22
April	32,658	2,887	14,891	6.42	7.16
May	16,808	6,711	10,714	4.62	5.32
June	7,424	2,787	4,420	1.91	2.13
July	3,833	1,612	2,671	1.15	1.32
August	5,035	1,925	2,788	1.20	1.38
September	1,955	1,348	1,590	.69	.77
October	5,137	1,547	2,224	.96	1.11
November	1,829	1,205	1,606	.69	.77
December	27,785	1,209	3,441	1.48	1.71
The year	32,653	1,205	4,211	1.82	24.67

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 21.

Estimated monthly discharge of Presumpscot River at outlet of Sebago Lake, Maine.

[Drainage area, 470 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	673	367	619	1.32	1.52
February	673	517	649	1.38	1.44
March	833	333	623	1.33	1.53
April	673	0	466	.99	1.10
May	728	333	605	1.29	1.49
June	993	400	722	1.54	1.72
July	747	300	670	1.43	1.65
August	693	300	575	1.22	1.41
September	673	300	596	1.27	1.41
October	687	283	574	1.22	1.41
November	717	233	618	1.31	1.46
December	700	200	616	1.31	1.51
The year	993	0	611	1.30	17.66

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 22.

A. STREET SCENE IN MADISON, ME., DURING FRESHET ON KENNEBEC RIVER.

B. DESTRUCTION OF PROPERTY AT SKOWHEGAN, ME., BY FRESHET ON KENNEBEC RIVER.

Estimated monthly discharge of Connecticut River at Orford, N. H.

[Drainage area, 3,050 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
August 6–31			2,326	0.76	0.75
September	2,600	945	1,414	.46	.51
October	11,378	1,952	4,317	1.42	1.64
November	13,798	1,653	7,016	2.30	2.56
December	6,780	3,988	5,051	1.66	1.91
1901.					
January			[a]3,500	1.15	1.33
February			[a]3,300	1.08	1.12
March			[a]5,849	1.92	2.21
April	23,478	10,228	17,972	5.89	6.57
May	13,919	5,486	8,769	2.88	3.32
June	7,990	2,686	5,186	1.70	1.90
July	8,111	1,340	3,334	1.09	1.26
August	6,540	1,205	3,642	1.19	1.37
September	2,188	1,205	1,644	.54	.60
October	5,148	1,393	2,302	.75	.86
November	2,432	1,393	1,701	.56	.62
December			[a]6,594	2.16	2.49
The year			5,149	1.74	23.65

[a] Approximate; river frozen.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 29; rating table on page 318 of same paper.

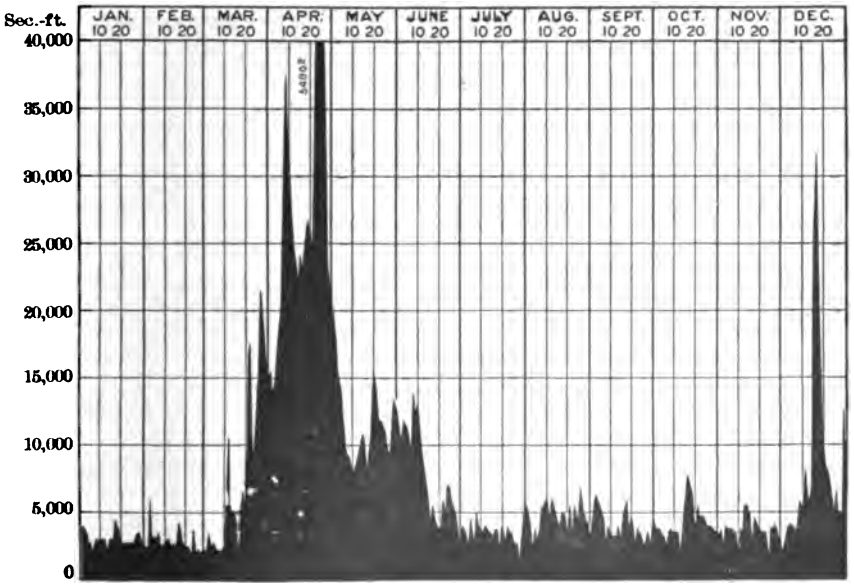


FIG. 4.—Discharge of Hudson River at Mechanicville, N. Y., 1901.

Estimated monthly discharge of Housatonic River at Gaylordsville, Conn.

[Drainage area, 1,020 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
October 23–31			358	0.35	0.12
November	550	240	909	.89	.99
December	3,890	810	1,544	1.51	1.74
1901.					
January	1,700	508	890	.87	1.00
February	682	324	489	.48	.50
March	16,845	458	4,269	4.19	4.84
April	12,285	2,600	6,280	6.16	6.87
May	6,525	2,600	4,432	4.34	5.01
June	4,845	745	2,067	2.03	2.26
July	885	508	674	.66	.76
August	6,285	458	1,458	1.43	1.65
September	1,700	745	1,088	1.07	1.19
October	6,045	745	1,639	1.61	1.86
November	2,035	562	1,108	1.09	1.22
December	12,525	745	3,872	3.80	4.39
The year	16,845	324	2,356	2.31	31.55

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 88; rating table on page 318 of same paper.

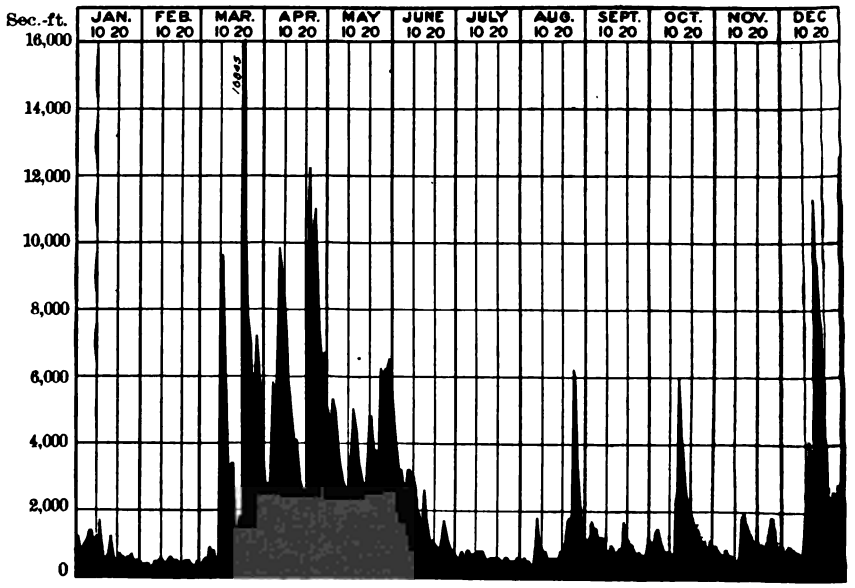


FIG. 5.—Discharge of Housatonic River at Gaylordsville, Conn., 1901

A. BLACKSTONE RIVER AT BERKELEY, R. I.

B. BLACKSTONE CANAL AT BERKELEY, R. I.

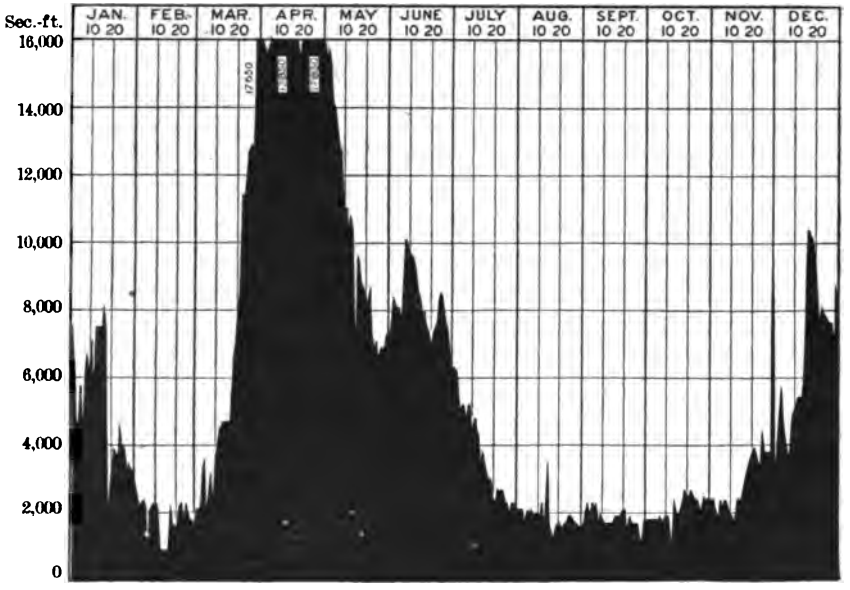


FIG. 6.—Discharge of Oswego River at high dam, New York, 1901.

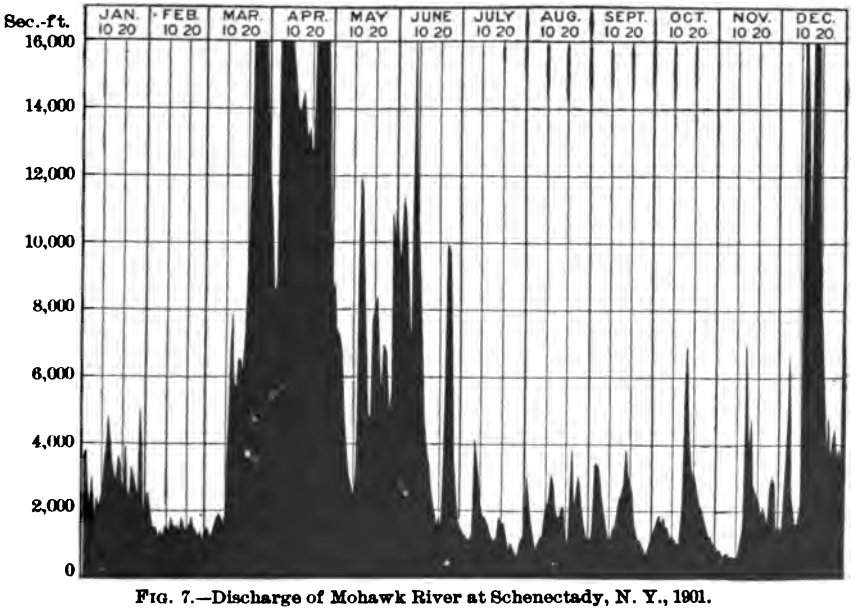


FIG. 7.—Discharge of Mohawk River at Schenectady, N. Y., 1901.

PASSAIC RIVER BASIN.

Gaging stations were established during 1901 on the Passaic River and on Pompton River, its principal tributary, at Two Bridges, N. J., by George B. Hollister, under whose direction systematic measurements are now being carried on. The two rivers drain areas of the

same extent, though different in character, the Pompton draining the high lands of northern New Jersey and part of New York State, while the Passaic flows through comparatively level lands. Following are the results of measurements for 1901:

Estimated monthly discharge of Passaic River at Two Bridges, N. J.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,000	623	1,105	3.07	3.54
June 1–22			779	2.16	1.76
July	1,007	137	448	1.24	1.43
August	3,858	363	1,409	3.91	4.51
September	1,650	271	632	1.76	1.96
October	959	225	472	1.31	1.51
November	719	181	321	.89	.99
December	4,445	225	1,015	2.82	3.26

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 211; rating table on page 318 of same paper.

Estimated monthly discharge of Pompton River at Two Bridges, N. J

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,751	893	1,529	4.25	4.90
June 1–22			1,015	2.82	2.30
July	1,254	195	541	1.50	1.73
August	5,342	255	1,834	5.09	5.86
September	2,240	221	848	2.35	2.62
October	1,181	221	533	1.48	1.71
November	1,001	195	322	.89	.99
December	6,328	300	1,441	4.00	4.61

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 212; rating table on page 318 of same paper.

A. TRENTON FALLS GORGE ON WEST CANADA CREEK, NEW YORK.

B. GAGING CATSKILL CREEK AT CAIRO, N. Y.

DELAWARE RIVER AND TRIBUTARIES NEAR PHILADELPHIA.

The gaging station on this river was established July 23, 1897, at Lambertville, N. J. Since its establishment continuous records have been kept of the flow of the river, which have been published in the annual reports, commencing with the Twentieth Annual Report, Part IV. The figures of discharge include in every instance the flow of the Delaware and Raritan Canal feeder. The record for 1901 is published herewith. Measurements of the flow of Perkiomen, Wissahickon, Tohickon, and Neshaminy creeks, all tributaries of Delaware River near Philadelphia, have been continued, as in former years, by Mr. John E. Codman, in charge of the hydrographic work of the bureau of water of the city of Philadelphia. The location of these creeks and the points of measurement are shown in fig. 16 of the Twentieth Annual Report, Part IV, page 89. On the following pages are given the records of these streams for 1901.

Estimated monthly discharge of Delaware River at Lambertville, N. J.

[Drainage area, 6,855 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	16,325	2,300	6,192	0.90	1.04
February			[a] 2,500	.37	.39
March	74,890	2,600	23,268	3.39	3.91
April	64,075	15,475	31,811	4.64	5.17
May	65,620	14,625	24,524	3.58	4.13
June	48,110	5,300	16,902	2.47	2.75
July	10,000	1,825	4,676	.68	.78
August	69,740	2,300	16,285	2.38	2.75
September	21,200	5,300	10,785	1.57	1.75
October	18,050	5,550	9,542	1.39	1.60
November	10,800	4,320	6,680	.97	1.08
December	161,410	6,375	31,366	4.58	5.28
The year			15,377	2.24	30.63

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 214; rating table on page 318 of same paper.

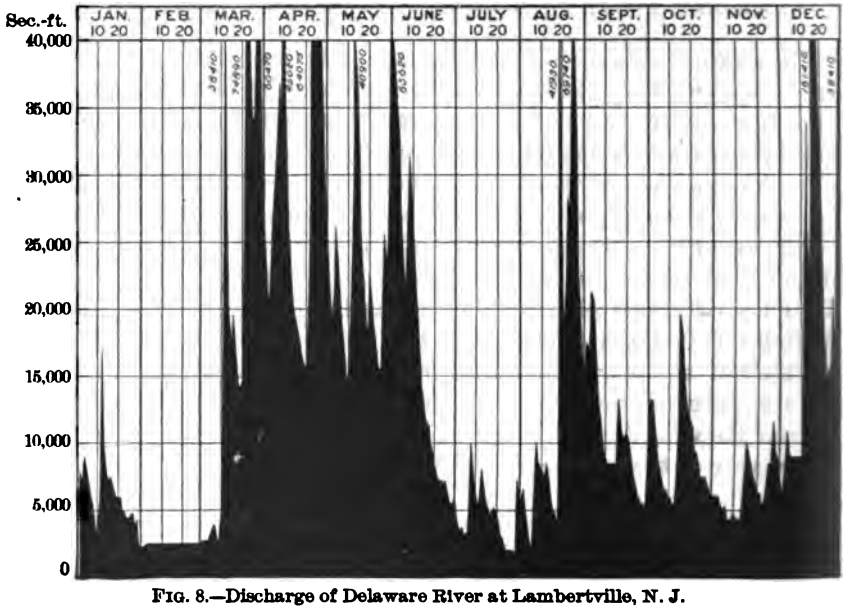


FIG. 8.—Discharge of Delaware River at Lambertville, N. J.

Estimated monthly discharge of Tohickon River at Point Pleasant, Pa.

[Drainage area, 102 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,768	12	145	1.42	1.64
February	11	4	9	.09	.09
March	3,353	9	461	4.52	5.11
April	2,388	31	372	3.63	4.05
May	1,219	7	202	1.98	2.28
June	289	3	58	.57	.64
July	7	3	5	.05	.06
August	893	4	123	1.21	1.40
September	608	7	40	.39	.44
October	52	5	17	.17	.20
November	201	4	27	.26	.29
December	4,039	19	622	6.10	7.02
The year	4,039	3	173	1.70	23.22

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 215.

Estimated monthly discharge of Neshaminy Creek, Pennsylvania, below the forks.

[Drainage area, 189 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,965	31	151	1.09	1.26
February	72	41	46	.33	.34
March	4,624	51	421	3.03	3.48
April	1,774	92	434	3.12	3.49
May	1,029	88	253	1.82	2.10
June	509	41	111	.80	.89
July	1,320	31	179	1.29	1.48
August	2,385	63	331	2.38	2.75
September	1,676	45	196	1.41	1.57
October	73	22	39	.28	.32
November	1,173	18	78	.56	.62
December	3,829	48	549	3.95	4.55
The year	4,624	18	232	1.67	22.85

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 216.

Estimated monthly discharge of Perkiomen Creek at Frederick, Pa.

[Drainage area, 152 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,623	31	139	0.91	1.05
February	84	29	44	.29	.30
March	4,717	46	441	2.91	3.35
April	2,237	58	337	2.22	2.48
May	1,113	67	236	1.55	1.79
June	547	36	119	.78	.87
July	137	12	44	.29	.33
August	1,433	36	184	1.21	1.40
September	250	38	87	.57	.64
October	260	31	80	.33	.61
November	368	36	72	.47	.52
December	6,017	51	557	3.67	4.22
The year	6,017	12	195	1.27	17.56

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 217.

Estimated monthly discharge of Wissahickon Creek, near Philadelphia, Pa.

[Drainage area, 65 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	240	12	54	0.83	0.96
February	64	16	38	.58	.60
March 1-9	24	17	18	.28	.09
August	1,095	19	138	2.12	2.45
September	99	20	32	.49	.55
October	48	16	30	.46	.53
November	515	13	37	.57	.64
December	1,269	17	133	2.05	2.37

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 218.

SUSQUEHANNA RIVER AND TRIBUTARIES.

During 1901 measurements have been made of Susquehanna River and its principal tributaries, as follows: North Branch of Susquehanna River at Wilkesbarre, Pa., and at Danville, Pa.; West Branch of Susquehanna River at Williamsport, Pa., and at Allenwood, Pa.; Juniata River at Newport, Pa., and Susquehanna River at Harrisburg, Pa. Owing to lack of sufficient discharge measurements the monthly figures of flow for the Williamsport, Wilkesbarre, and Allenwood stations were not computed for 1901. Results for the other stations are given in the following tables, the figures of discharge for the Susquehanna at Harrisburg including the flow of the Pennsylvania Canal at that point:

Estimated monthly dischage of North Branch of Susquehanna River at Danville, Pa.

[Drainage area, 11,070 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January			[a]30,000	2.71	3.12
February			[a]30,000	2.71	2.82
March			[a]52,136	4.71	5.43
April	88,640	22,400	38,120	3.44	3.84

Estimated monthly discharge of North Branch of Susquehanna River at Danville, Pa.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May	83,600	14,310	25,209	2.28	2.63
June	74,960	6,800	20,223	1.83	2.04
July	6,400	2,500	4,079	.37	.43
August	56,240	2,750	12,646	1.14	1.31
September	13,135	3,300	6,042	.55	.61
October	8,100	3,600	5,535	.50	.58
November	27,440	2,750	6,412	.58	.65
December	139,760	7,200	35,246	3.18	3.67
The year	139,760	2,500	22,121	2.00	27.13

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 220; rating table on page 318 of same paper.

Estimated monthly discharge of Juniata River at Newport, Pa.

[Drainage area, 3,476 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,500	1,200	2,224	0.64	0.74
February	4,000	1,600	2,634	.76	.79
March	59,500	2,040	12,155	3.50	4.04
April	49,000	5,850	16,957	4.88	5.45
May	46,500	3,250	13,187	3.79	4.37
June	24,000	3,250	6,792	1.95	2.18
July	6,900	1,600	2,845	.82	.95
August	11,150	1,200	3,880	1.12	1.29
September	7,700	1,400	3,134	.90	1.00
October	2,270	1,000	1,447	.42	.48
November	5,850	1,000	1,637	.47	.52
December	70,000	2,040	13,731	3.95	4.55
The year	70,000	1,000	6,719	1.93	26.36

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 226; rating table on page 318 of same paper.

Estimated monthly discharge of Susquehanna River at Harrisburg, Pa.

[Drainage area, 24,030 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	27,925	7,830	14,498	0.60	0.69
February	35,400	11,900	20,236	.84	.87
March	193,160	11,125	82,431	3.43	3.96
April	205,690	47,275	105,569	4.39	4.90
May	211,060	27,925	63,966	2.66	3.07
June	187,790	24,500	55,296	2.30	2.56
July	24,500	10,100	14,012	.58	.67
August	123,350	8,475	33,663	1.40	1.61
September	54,435	11,125	22,262	.93	1.04
October	19,800	9,450	13,669	.57	.66
November	58,910	6,880	15,265	.64	.71
December	347,100	15,100	70,990	2.95	3.41
The year	347,100	6,880	42,655	1.77	24.15

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 227; rating table on page 318 of same paper.

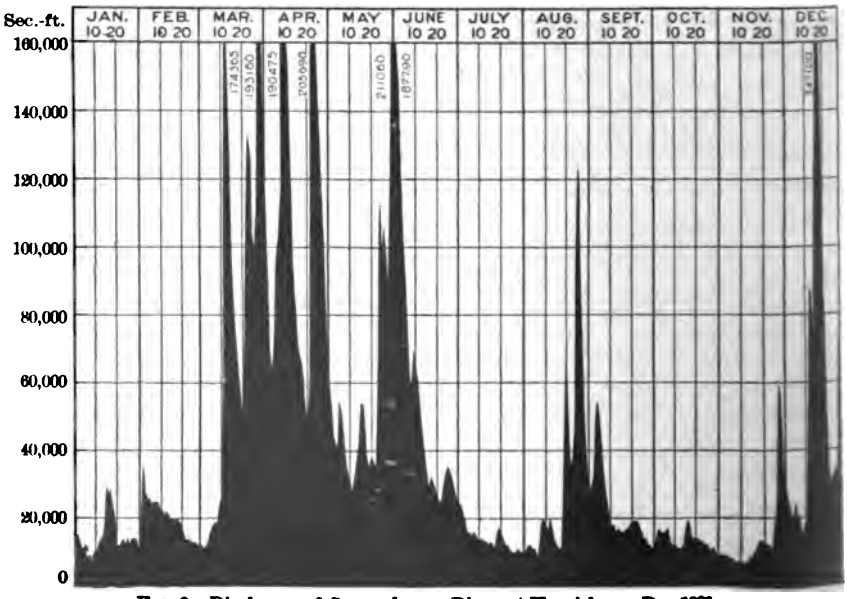


FIG. 9.—Discharge of Susquehanna River at Harrisburg, Pa., 1901.

PATAPSCO RIVER.

The river rises in the north central part of Maryland and empties into Chesapeake Bay about 13 miles below Baltimore. Its watershed is a hilly country, largely under cultivation. The station at Woodstock, Md., was established August 6, 1896, since which time continuous records have been kept, which have been published in former annual reports. The record for 1901 is given herewith.

Estimated monthly discharge of Patapsco River at Woodstock, Md.

[Drainage area, 251 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	670	122	207	0.82	0.95
February	310	186	239	.95	.99
March	5,075	252	792	3.16	3.64
April	2,102	160	508	2.02	2.25
May	1,600	160	380	1.51	1.74
June	1,100	91	276	1.10	1.23
July	1,600	100	245	.98	1.13
August	5,280	66	366	1.46	1.68
September [a]					
October	590	111	209	.83	.96
November	2,000	91	239	.95	1.06
December	8,048	310	1,014	4.04	4.66

[a] No record.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 228; rating table on page 318 of same paper.

POTOMAC RIVER AND TRIBUTARIES.

Potomac River is formed by the junction of the North and South branches, about 15 miles below Cumberland, Md. Regular gaging stations have been maintained on the North Branch at Piedmont, W. Va., on the South Branch near Springfield, W. Va., on Antietam Creek near Sharpsburg, Md., on the North Branch of Shenandoah River near Riverton, Va., on the South Branch of Shenandoah River near Front Royal, Va., on Shenandoah River at Millville, W. Va., on Potomac River at Point of Rocks, Md., and on Monocacy River near Frederick, Md. During a flood in the early part of 1902 the bridge and the gage near Springfield were carried away and the sta-

tion was abandoned. It was established June 26, 1899, and the results of the measurements for the entire period are published below.

Estimated monthly discharge of North Branch of Potomac River at Piedmont, W. Va.

[Drainage area, 407 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,360	336	682	1.68	1.94
February	705	305	403	.99	1.03
March	3,480	305	1,258	3.09	3.56
April	4,280	672	1,810	4.45	4.97
May	4,200	475	1,422	3.49	4.02
June	1,720	390	937	2.30	2.57
July	3,400	175	482	1.18	1.36
August	1,800	149	423	1.04	1.20
September	430	124	224	.55	.61
October	230	100	130	.32	.37
November	352	77	137	.34	.38
December	5,240	202	1,271	3.12	3.60
The year	5,240	77	765	1.88	25.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 229; rating table on page 318 of same paper.

Estimated monthly discharge of South Branch of Potomac River near Springfield, W. Va.

[Drainage area, 1,440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	730	240	358	0.25	0.29
August	400	250	286	.20	.23
September	400	250	333	.23	.26
October	890	250	332	.23	.27
November	2,240	400	1,134	.79	.88
December	2,150	335	1,051	.73	.84

Estimated monthly discharge of South Branch of Potomac River near Springfield, W. Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	4,335	500	1,154	.80	.92
February	3,750	1,500	2,576	1.79	1.86
March	5,415	1,070	3,129	2.17	2.51
April	3,600	285	1,486	1.03	1.15
May	890	265	507	.35	.40
June	6,135	540	1,728	1.20	1.34
July	1,790	250	856	.59	.68
August	730	230	331	.23	.27
September	980	230	347	.24	.27
October	600	285	367	.26	.30
November	5,685	265	1,085	.75	.84
December	5,685	335	1,307	.91	1.05
The year	6,135	230	1,239	.86	11.59
1901.					
January	4,425	335	1,151	0.80	0.92
February	600	500	518	.36	.38
March	7,575	490	2,216	1.54	1.78
April	10,185	730	3,777	2.62	2.92
May	8,295	980	2,910	2.02	2.33
June	7,035	890	2,441	1.70	1.90
July	3,050	250	1,316	.91	1.05
August	980	265	498	.35	.40
September	4,380	285	774	.54	.60
October	1,070	265	357	.25	.29
November	1,610	250	375	.26	.29
December	9,735	335	2,611	1.81	2.09
The year	10,185	250	1,579	1.10	14.95

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 239; rating table on page 318 of same paper.

Estimated monthly discharge of Antietam Creek near Sharpsburg, Md.

[Drainage area, 298 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	123	60	76	0.26	0.30
February	154	48	79	.27	.28
March	2,241	60	293	1.00	1.15
April	2,127	416	649	2.22	2.48
May	2,543	249	532	1.82	2.10
June	485	281	359	1.23	1.37
July	382	154	255	.87	1.00
August	1,058	123	225	.77	.89
September	416	95	171	.58	.65
October	281	75	123	.42	.48
November 1–16			83	.28	.31

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 230; rating table on page 318 of same paper.

Estimated monthly discharge of North Branch of Shenandoah River near Riverton, Va.

[Drainage area, 1,034 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,645	215	676	0.65	0.75
February	380	240	288	.28	.29
March	11,270	190	1,378	1.33	1.53
April	15,870	747	3,622	3.50	3.90
May	13,915	920	2,578	2.49	2.87
June	10,925	1,265	2,787	2.70	3.01
July	4,945	530	1,597	1.54	1.78
August	3,450	430	960	.93	1.07
September	2,760	165	740	.72	.80
October	1,610	190	406	.39	.45
November	2,070	140	376	.36	.40
December	14,145	270	2,911	2.82	3.25
The year	15,870	140	1,527	1.48	20.10

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 231; rating table on page 319 of same paper.

Estimated monthly discharge of South Branch of Shenandoah River near Front Royal, Va.

[Drainage area, 1,569 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	915	385	493	0.31	0.36
August	1,250	315	556	.35	.40
September	2,050	440	717	.46	.51
October	640	410	514	.33	.38
November	6,070	605	1,205	.77	.86
December	4,090	470	1,093	.70	.81
1900.					
January	10,840	915	2,186	1.39	1.60
February	7,600	915	2,400	1.53	1.59
March	10,750	1,640	3,482	2.22	2.56
April	3,640	1,100	1,744	1.11	1.24
May	1,975	675	1,127	.72	.83
June	5,890	605	1,703	1.09	1.22
July	1,100	470	736	.46	.53
August	750	360	493	.31	.36
September	1,052	315	457	.29	.32
October	4,090	502	1,020	.65	.75
November	6,790	535	1,255	.80	.89
December	5,260	675	1,394	.89	1.03
The year	10,840	315	1,500	.96	12.92

Estimated monthly discharge of South Branch of Shenandoah River near Front Royal, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,260	470	1,353	0.87	1.00
February	1,200	535	779	.50	.52
March	11,020	470	1,909	1.22	1.41
April	27,580	1,580	6,611	4.21	4.69
May	23,980	1,640	4,920	3.14	3.62
June	11,380	1,900	4,279	2.73	3.04
July	13,180	1,410	3,834	2.44	2.82
August	6,340	1,052	3,259	2.08	2.40
September	7,600	675	1,807	1.15	1.28
October	9,220	712	1,772	1.13	1.30
November	2,920	605	930	.59	.66
December	27,580	1,200	4,658	2.97	3.43
The year	27,580	470	3,009	1.92	26.17

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 232; rating table on page 319 of same paper.

Estimated monthly discharge of Shenandoah River at Millville, W. Va.

[Drainage area, 2,995 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,790	840	1,828	0.61	0.70
February	1,950	740	1,272	.42	.44
March	17,840	840	3,302	1.10	1.27
April	29,520	2,515	10,612	3.54	3.95
May	29,840	2,600	7,674	2.56	2.96
June	26,640	3,740	7,592	2.54	2.83
July	12,880	1,310	4,344	1.45	1.67
August	2,780	1,725	3,480	1.16	1.34
September	11,280	1,250	2,487	.83	.93
October	6,320	1,140	1,784	.60	.69
November	3,950	940	1,366	.46	.51
December	30,160	1,370	6,421	2.14	2.47
The year	30,160	740	4,347	1.45	19.76

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 233; rating table on page 319 of same paper.

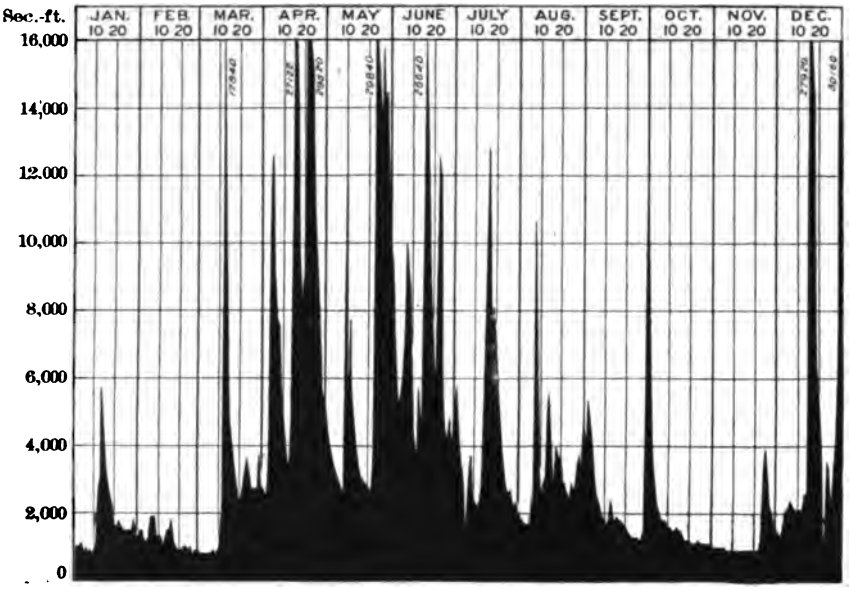


FIG. 10.—Discharge of Shenandoah River at Millville, W. Va., 1901.

Estimated monthly discharge of Potomac River at Point of Rocks, Md.

[Drainage area, 9,654 square miles]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,560	1,860	4,923	0.51	0.59
February	6,020	2,360	3,578	.37	.39
March	86,610	2,360	13,976	1.45	1.67
April	172,150	7,000	40,829	4.23	4.72
May	111,180	6,020	28,747	2.98	3.44
June	49,300	7,980	19,398	2.00	2.23
July	27,050	4,700	10,715	1.11	1.28
August	20,950	3,950	8,256	.86	.99
September	28,270	3,600	7,539	.78	.87
October	11,900	2,630	4,206	.44	.51
November	20,340	2,380	4,681	.48	.54
December	139,390	4,300	26,426	2.74	3.16
The year	172,150	1,860	14,440	1.50	20.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 233; rating table on page 319 of same paper.

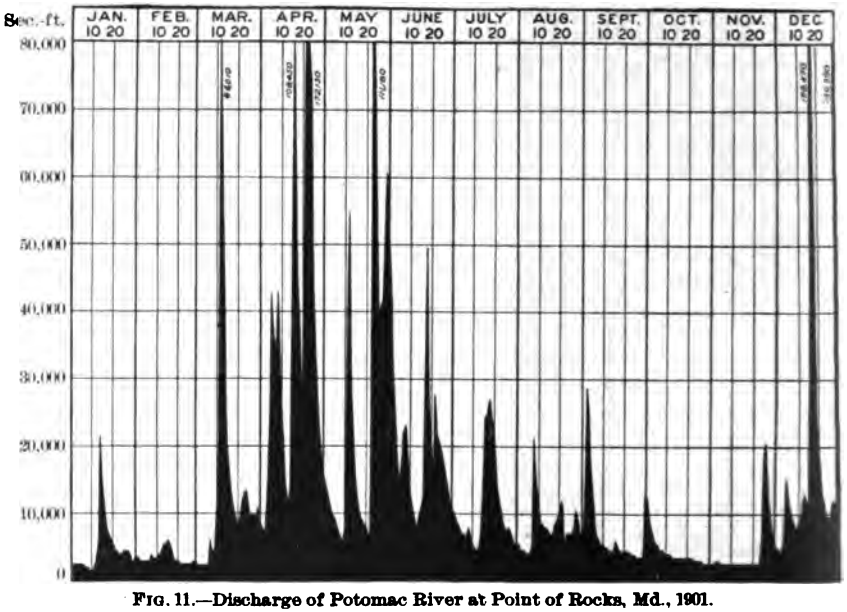


FIG. 11.—Discharge of Potomac River at Point of Rocks, Md., 1901.

Estimated monthly discharge of Monocacy River near Frederick, Md.

[Drainage area, 665 square miles].

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,170	150	461	0.69	0.80
February	550	240	347	.52	.54
March	15,984	270	2,085	3.14	3.62
April	14,264	700	2,650	3.98	4.44
May	5,750	420	1,521	2.29	2.64
June	2,740	305	875	1.32	1.47
July	750	180	332	.50	.58
August	1,966	150	464	.70	.81
September	1,622	180	311	.47	.52
October	600	180	283	.43	.50
November	3,944	210	495	.74	.83
December	14,264	380	2,193	3.30	3.81
The year	15,984	150	1,001	1.51	20.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 234; rating table on page 319 of same paper.

JAMES RIVER AND TRIBUTARIES.

Records of measurements have been kept as in previous years on North (of James) River at Glasgow, Va.; on James River at Buchanan, Va., Holcomb Rock, Va., and at Cartersville, Va. A station was established on Appomattox River at Mattoax, Va., on August 26, 1900, and was maintained during 1901. The results of measurements at this station for the entire period are given below. No results are here given for the station at Holcomb Rock, as no discharge measurements are made at that place.

Estimated monthly discharge of North (of James) River at Glasgow, Va.

[Drainage area, 831 square miles.]

Month.	Discharge in second-feet.			Run-off	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,602	280	751	0.90	1.04
February	400	280	339	.41	.43
March	7,050	280	1,757	2.11	2.44
April	12,170	720	3,124	3.76	4.20
May	12,170	650	1,996	2.40	2.77
June	14,015	685	2,246	2.69	3.00
July	2,100	400	847	1.02	1.18
August	7,050	330	1,793	2.16	2.49
September	3,008	450	724	.87	.97
October	845	280	395	.48	.55
November	450	250	289	.35	.39
December	24,060	280	3,240	3.90	4.50
The year	24,060	250	1,418	1.75	23.96

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 285; rating table on page 319 of same paper.

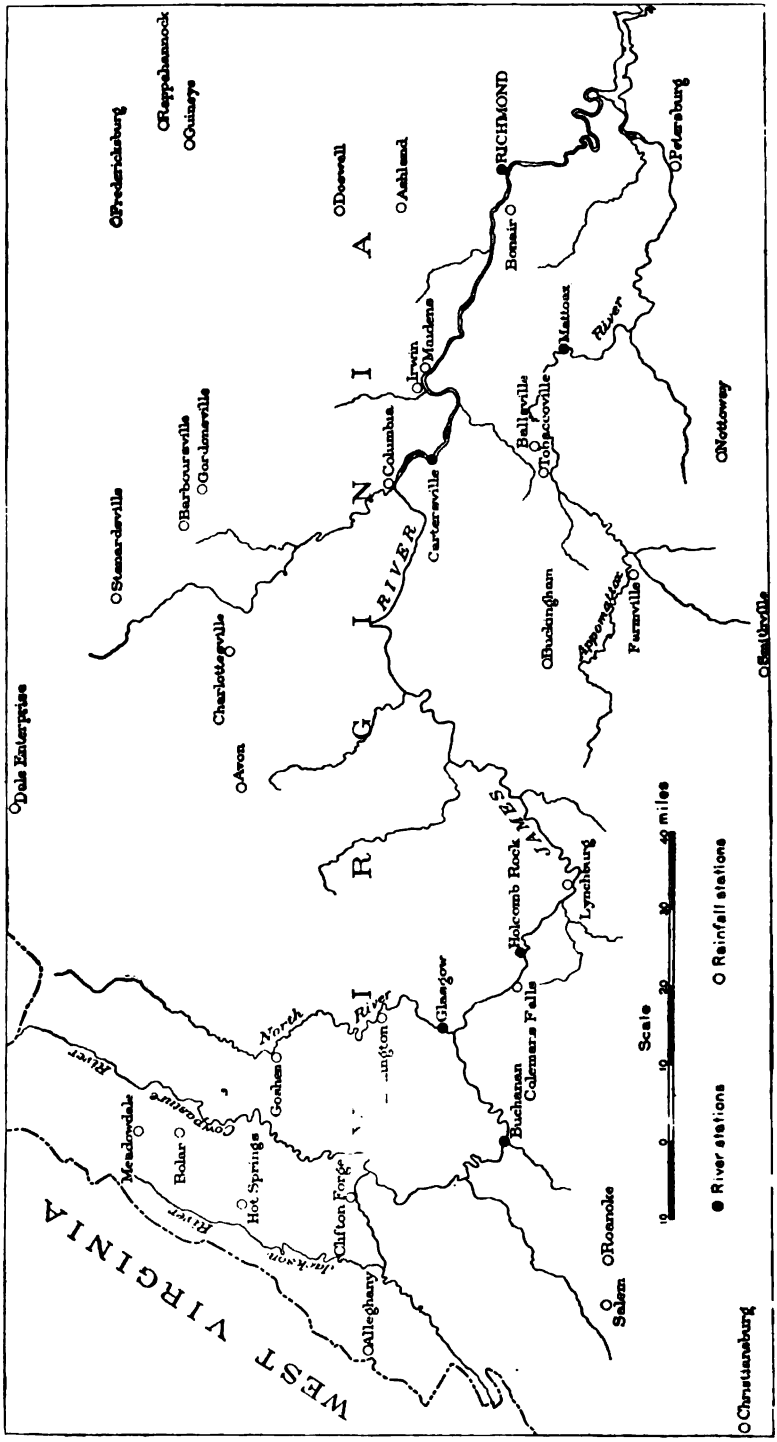


FIG. 12.—Location of river and rainfall stations in basin of James River.

Estimated monthly discharge of James River at Buchanan, Va.

[Drainage area, 2,058 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	18,956	750	2,739	1.33	1.53
February	1,980	750	1,234	.60	.62
March	16,580	750	3,786	1.84	2.12
April	25,820	2,870	8,589	4.17	4.65
May	31,620	1,650	5,882	2.86	3.30
June	25,028	1,980	5,609	2.72	3.03
July	6,185	840	2,594	1.26	1.45
August	20,276	750	4,683	2.27	2.62
September	9,980	670	1,605	.78	.87
October	1,650	540	726	.35	.40
November	840	430	518	.25	.28
December	48,260	540	6,736	3.27	3.77
The year	48,260	430	3,725	1.81	24.64

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 236; rating table on page 319 of same paper.

Estimated monthly discharge of James River at Cartersville, Va.

[Drainage area, 6,232 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,880	2,755	9,220	1.48	1.71
February	4,666	2,668	3,648	.59	.61
March	29,600	2,411	8,217	1.32	1.52
April	62,765	6,765	24,509	3.93	4.38
May	75,800	5,300	17,762	2.85	3.29
June	53,360	7,240	17,172	2.76	3.08
July	17,390	3,021	7,750	1.24	1.43
August	47,090	2,496	16,668	2.67	3.08
September	26,300	3,294	6,836	1.10	1.23
October	12,200	2,327	3,725	.60	.69
November	9,390	2,078	2,816	.45	.50
December	75,470	2,582	15,926	2.56	2.95
The year	75,800	2,078	11,187	1.80	24.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 238; rating table on page 319 of same paper.

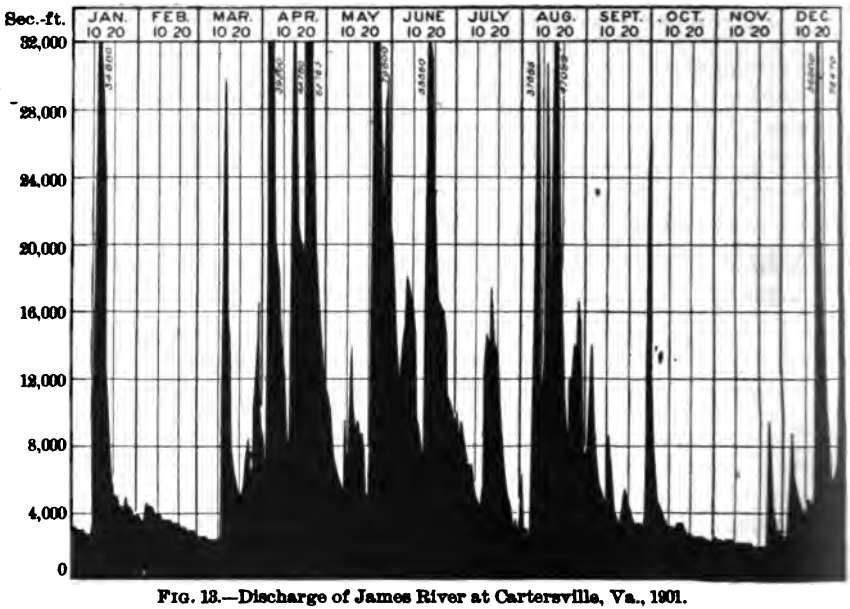


FIG. 13.—Discharge of James River at Cartersville, Va., 1901.

Estimated monthly discharge of Appomattox River at Mattoax, Va.

[Drainage area, 745 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	663	78	171	0.23	0.26
October	277	153	183	.24	.28
November	487	171	232	.31	.35
December	1,600	165	383	.51	.59
1901.					
January	5,560	243	986	1.32	1.52
February	580	249	339	.45	.47
March	2,755	243	517	.69	.80
April	8,050	378	2,433	3.26	3.64
May	12,050	279	2,084	2.79	3.22
June	825	243	427	.57	.64
July	2,160	195	524	.70	.81
August	6,550	165	2,664	3.57	4.12
September	1,680	261	446	.60	.67
October	1,280	249	333	.45	.52
November	1,120	249	314	.42	.47
December	5,950	285	1,456	1.96	2.26
The year	12,050	165	1,043	1.40	19.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, on page 238; rating table on page 319 of same paper.

PRECIPITATION IN THE BASIN OF JAMES RIVER.

The principal observations of rainfall made within the James River Basin are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of the points is shown in fig. 12, in connection with the points of river measurement, which are located at Buchanan, Glasgow, Holcomb Rock, Cartersville, and Mattoax.

Location of rainfall stations in James River Basin.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Ashland	Hanover	Virginia	37 45	77 30	220	9-10
Barboursville	Orange	do			500	5-6
Bedford City	Bedford	do			900	10-12
Bonair	Chesterfield	do			325	7-8
Buckingham	Buckingham	do			550	5-8
Christiansburg	Montgomery	do	37 5	80 23	2,760	12-15
Clifton Forge	Alleghany	do	37 50	79 55	1,047	4-6
Dale Enterprise	Rockingham	do	38 40	78 45	850	22
Doswell	Hanover	do			134	4-5
Farmville	Prince Edward	do			316	3-5
Fredericksburg	Spottsylvania	do			47	7-9
Hot Springs	Bath	do			2,195	7-10
Lexington	Rockbridge	do			946	25-31
Lynchburg	Campbell	do	37 25	79 9	681	29-31
Petersburg	Dinwiddie	do	37 12	77 20	11	14-16
Richmond	Henrico	do	37 32	77 26	172	22-24
Salem	Roanoke	do				11-12
Stanardsville	Greene	do			1,150	10-11
Staunton	Augusta	do	38 9	79 4	1,340	13-16

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896 to 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of James River.

ASHLAND, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.98	3.33	3.41	3.78	4.90	3.36	5.25	3.53	3.65	3.70	2.57	2.45	42.86
1896	2.35	3.56	4.12	2.00	3.37	3.67	6.64	1.46	5.49	.56	2.42	.51	36.15
1897	1.52	6.26	4.56	2.82	3.01	3.64	4.98	2.23	.80	6.93	3.47	2.67	42.89
1898	1.61	.78	4.18	5.09	6.05	3.94	4.42	4.82	2.86	4.33	1.98	3.33	43.34
1899	3.84	4.60	5.82	1.11	3.14	2.38	6.76	5.11	4.48	3.98	1.57	2.42	45.21
1900	3.29	5.09	2.62	3.42	2.59	5.25	1.62	1.21	3.47	3.63	2.43	2.83	37.45
1901	3.11	.36	3.82	5.66	6.46	1.40	6.82	10.13	3.89	1.40	1.40	5.40	49.85

Precipitation at stations in drainage basin of James River—Continued.

BARBOURSVILLE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.04	3.36	3.45	3.40	5.58	4.10	4.43	3.98	3.86	2.23	2.52	3.66	42.61
1896	(3.04)	(3.36)	(3.45)	(3.40)	(5.58)	(4.10)	(4.43)	(3.98)	6.40	.28	4.02	.05	42.10
1897	1.76	5.56	2.71	2.06	6.04	3.63	4.50	1.08	.80	4.56	2.16	3.92	38.73
1898	2.80	.72	4.68	3.19	7.66	3.97	4.69	(3.98)	(3.86)	(2.28)	(2.52)	(3.66)	43.95
1899	3.76	5.65	(3.45)	1.81	2.50	2.80	5.46	3.14	4.90	3.50	1.55	3.01	41.53
1900	4.17	4.45	3.60	2.50	1.41	5.63	1.60	2.72	4.34	2.35	2.48	2.80	38.05
1901	2.73	.42	2.80	7.46	10.28	4.46	5.89	9.00	2.87	.47	2.37	8.51	57.26

BEDFORD CITY, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.89	3.54	3.21	3.13	4.21	3.58	3.75	4.76	3.69	3.31	2.33	3.29	41.49
1896	2.16	4.30	5.13	1.89	1.82	(3.58)	(3.75)	3.55	6.75	(3.31)	5.00	(3.29)	44.53
1897	(2.89)	(3.54)	3.10	1.50	3.70	3.68	1.70	.87	1.00	3.63	2.52	3.55	31.68
1898	2.48	1.02	4.03	3.21	7.81	2.53	4.26	3.67	4.08	8.66	2.05	4.16	47.96
1899	3.96	(3.54)	(3.21)	(3.13)	(4.21)	5.76	5.22	6.86	4.27	2.18	.69	1.82	44.85
1900	4.39	5.57	1.56	3.98	2.92	4.67	3.65	1.31	5.30	2.93	1.87	4.25	42.35
1901	2.68	.90	3.72	6.13	4.99	4.24	5.07	15.17	2.73	.43	1.34	8.10	55.50

BONAIR, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.19	3.89	4.31	4.13	3.93	3.09	5.03	3.71	3.61	3.44	2.73	3.17	43.73
1896	2.98	4.21	3.98	2.22	4.21	6.11	7.13	1.26	4.61	.89	3.27	1.27	41.94
1897	1.90	6.27	5.00	2.62	2.46	2.11	3.74	1.73	.86	6.52	4.37	4.01	41.69
1898	1.72	.81	3.43	4.71	6.95	2.34	3.50	4.74	3.22	4.89	2.93	3.25	42.49
1899	4.23	5.85	6.28	1.48	2.16	2.83	4.24	5.34	5.55	3.43	.86	1.95	44.30
1900	2.54	4.10	2.58	4.37	2.47	3.57	2.49	1.15	3.64	3.97	2.99	3.00	36.87
1901	3.79	.69	4.28	5.63	4.19	2.61	8.86	9.66	3.31	.99	7.71	6.94	52.66

BUCKINGHAM, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.32	3.46	3.94	3.24	4.19	2.83	3.81	4.76	4.14	3.13	2.24	2.89	41.95
1896	3.30	3.74	(3.94)	2.02	4.96	4.41	6.08	2.27	4.83	.29	3.79	T.	39.63
1897	.92	6.70	3.56	2.95	3.02	1.90	2.92	.73	1.05	4.72	3.47	2.77	34.71
1898	2.00	.40	2.23	3.20	3.53	1.75	5.00	3.90	2.08	6.60	2.17	3.56	36.42
1899	4.53	5.61	8.05	1.94	4.36	3.29	2.97	7.46	4.76	3.35	.88	1.70	40.99
1900	3.62	5.42	3.45	2.92	2.65	5.62	3.21	2.22	2.66	2.10	3.46	3.03	40.35
1901	3.49	.59	2.40	6.40	[a]6.47	2.46	2.49	18.75	6.02	.46	.30	7.43	[a]52.26

CHRISTIANSBURG, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.63	3.08	3.55	2.36	4.30	3.63	3.60	3.53	3.59	3.12	1.95	2.13	37.47
1896	1.07	2.64	6.36	2.80	3.91	3.76	6.94	1.21	5.20	1.15	3.72	.60	39.36
1897	1.59	6.80	3.62	1.76	2.88	2.04	4.34	3.23	2.13	3.88	.81	3.66	36.74
1898	2.78	.30	3.08	1.93	5.86	2.52	4.21	3.13	4.17	5.11	2.28	2.54	38.00
1899	4.07	4.97	7.11	3.36	3.39	4.52	2.64	2.92	4.01	1.11	2.42	2.08	42.60
1900	2.09	3.53	5.37	2.24	4.34	8.87	1.37	2.38	5.67	3.85	3.10	3.20	46.01

CLIFTON FORGE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.08	3.05	3.49	2.69	4.51	3.17	2.78	3.05	3.15	2.97	2.69	1.65	35.28
1896	(2.08)	(3.05)	(3.49)	(2.69)	(4.51)	(3.17)	(2.78)	(3.05)	6.43	.28	5.56	T.	37.09
1897	2.35	5.19	3.35	1.13	4.46	3.83	3.78	4.32	.46	2.87	2.64	3.54	37.92
1898	2.66	.51	3.24	2.58	4.13	1.28	3.69	2.78	3.65	7.92	(2.69)	2.33	37.46
1899	1.49	4.29	3.70	(2.69)	(4.51)	1.65	1.42	2.12	.31	.89	.38	1.23	24.09
1900	1.78	4.92	2.67	2.10	3.80	4.23	2.25	.77	5.02	5.46	4.11	.80	37.91
1901	2.12	.35	4.50	4.96	5.65	4.85	(2.78)	5.24	3.02	.40	.76	2.00	36.63

[a] Incomplete.

Precipitation at stations in drainage basin of James River—Continued.

DALE ENTERPRISE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.68	3.19	3.26	3.17	4.87	5.36	4.31	3.89	3.95	2.92	2.39	2.63	42.62
1896	1.75	3.40	3.70	1.19	1.99	5.17	5.69	1.55	7.85	.16	4.30	.....	34.73
1897	1.56	5.64	2.40	1.70	5.37	2.88	4.15	.68	.43	2.55	2.40	3.23	32.99
1898	2.37	.61	3.90	2.91	4.94	4.83	6.24	9.54	2.23	7.39	1.82	3.60	50.38
1899	1.87	5.57	4.34	1.21	3.75	1.86	3.15	2.18	4.40	1.75	.91	1.00	31.99
1900	3.20	2.87	3.38	1.70	2.06	8.01	3.47	2.44	3.22	2.45	3.11	1.61	37.52
1901	2.04	.28	3.86	5.78	5.11	14.37	4.83	6.36	3.84	2.06	1.39	6.37	56.29

DOSWELL, VA.

Normal	2.93	2.20	3.37	3.15	3.21	2.46	3.35	4.14	2.68	2.97	3.02	1.98	35.46
1897	3.15	(2.20)	4.10	1.90	2.70	2.38	2.09	2.40	.70	5.60	2.57	2.80	32.59
1898	1.60	.79	4.35	5.23	3.82	2.26	5.23	(4.14)	2.80	(2.97)	3.47	1.16	37.82
1899	4.26	4.68	4.90	.96	2.45	2.22	2.45	(4.14)	4.50	2.02	(3.02)	(1.98)	37.58
1900	(2.93)	3.32	1.50	2.89	2.40	2.28	2.01	.92	1.58	2.73	(3.02)	(1.98)	27.56
1901	2.72	.02	1.98	4.78	4.68	3.14	4.99	9.11	3.82	1.51	(3.02)	(1.98)	41.75

FARMVILLE, VA.

Normal	2.38	4.24	4.59	3.25	4.88	4.33	4.77	3.16	2.41	2.65	1.78	2.51	40.95
1897	(2.38)	(4.24)	4.20	1.01	3.65	3.85	6.93	.33	T.	4.83	1.50	1.91	34.83
1898	.65	(4.24)	3.09	4.23	5.49	2.80	6.63	3.67	3.01	4.81	2.25	3.35	44.22
1899	3.55	6.14	9.72	1.82	2.84	4.61	2.50	8.02	2.98	2.01	1.95	1.02	47.16
1900	(2.38)	5.15	2.87	3.30	2.48	8.19	3.58	1.82	2.68	1.48	1.82	4.00	39.75
1901	2.95	1.45	3.10	6.00	9.97	2.20	4.20	1.95	3.40	.10	1.40	[a]2.30	[a]39.02

FREDERICKSBURG, VA.

Normal	2.63	3.82	3.47	3.54	4.67	3.62	4.06	3.37	2.95	3.42	2.18	2.93	40.66
1896	1.54	3.65	3.85	1.90	4.60	5.41	5.50	1.28	4.93	.14	2.60	.08	35.48
1897	1.70	6.40	3.02	2.31	4.59	3.63	5.04	2.04	.68	5.25	1.99	3.17	39.82
1898	3.17	1.19	4.55	4.28	7.47	2.02	3.10	4.44	1.19	5.39	2.07	4.01	42.88
1899	4.61	6.79	5.41	1.50	5.18	3.40	3.39	4.45	5.36	4.38	1.59	1.82	47.88
1900	3.16	4.73	3.00	3.83	1.17	7.09	2.81	.96	4.36	5.32	2.09	3.43	41.95
1901	3.09	.50	3.02	6.34	3.89	2.56	5.33	8.23	2.48	.46	1.58	7.90	45.38

HOT SPRINGS, VA.

Normal	2.42	3.87	3.21	2.83	4.36	4.16	3.89	3.39	3.35	3.27	2.11	3.11	39.97
1896	(2.42)	3.68	5.80	.94	3.63	3.79	4.47	4.16	6.42	.47	5.16	.19	41.13
1897	2.15	6.96	2.89	1.21	5.73	3.52	3.26	1.08	.63	2.11	2.02	3.98	35.54
1898	1.99	.79	4.10	(2.83)	(4.36)	(4.16)	5.11	8.00	3.90	11.80	(2.11)	2.73	51.88
1899	2.84	8.18	5.91	1.58	2.34	3.78	6.72	3.45	.36	5.24	.50	1.23	42.13
1900	2.31	5.86	2.84	1.79	3.50	4.46	5.25	1.79	4.91	4.33	(2.11)	2.70	41.85
1901	2.33	.23	3.91	8.26	7.74	6.22	3.79	6.22	4.20	.70	2.35	9.50	55.45

LEXINGTON, VA.

Normal	3.35	3.27	3.39	3.03	3.79	3.62	3.98	3.73	4.03	2.85	2.90	2.75	40.69
1896	2.93	4.21	4.97	1.11	1.55	4.31	8.10	5.65	5.88	.31	5.35	.15	44.52
1897	1.76	5.79	3.44	1.58	4.63	3.33	3.99	3.03	1.09	2.56	2.44	3.42	37.06
1898	2.58	.77	3.47	2.59	5.81	4.72	4.44	6.24	3.61	7.83	2.10	2.90	47.06
1899	3.79	5.41	6.69	1.25	5.00	2.62	3.18	5.41	4.01	2.08	.50	1.47	41.41
1900	2.92	4.38	4.03	2.73	2.70	7.49	3.12	1.12	3.79	3.08	2.73	2.21	40.30
1901	3.00	.57	3.97	5.40	4.61	(3.62)	(3.98)	(3.73)	(4.03)	(2.05)	1.32	8.12	44.40

[a] Incomplete.

Precipitation at stations in drainage basin of James River—Continued.

LYNCHBURG, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.89	3.63	3.91	3.28	4.16	3.62	4.20	4.13	3.89	3.25	2.88	3.15	43.99
1896	2.30	4.54	5.54	1.61	5.01	3.82	3.58	2.04	7.06	1.07	4.92	.13	46.64
1897	2.19	7.84	3.46	2.08	4.27	2.70	6.75	.94	1.12	3.12	2.24	3.37	40.08
1898	2.16	.74	3.25	2.94	9.08	2.98	7.17	2.82	4.50	7.33	2.61	4.35	49.93
1899	4.95	5.86	9.01	1.52	2.99	4.84	3.87	7.50	4.54	3.87	2.22	1.74	52.91
1900	4.36	4.38	4.35	3.74	4.07	3.81	1.92	2.29	4.78	3.49	2.31	3.10	47.10
1901	3.59	.78	3.66	5.98	5.34	4.93	4.38	12.36	3.17	.48	1.47	3.72	54.81

PETERSBURG, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.62	3.61	4.55	3.79	5.22	3.73	4.84	3.73	4.13	3.44	2.80	2.56	45.02
1896	2.58	4.64	3.33	1.91	7.25	5.90	3.33	.70	3.05	.63	2.58	1.93	42.73
1897	1.96	5.85	5.71	2.52	3.40	2.19	2.72	1.20	1.69	4.88	2.78	2.66	37.56
1898	1.21	.78	3.95	4.90	5.35	2.57	4.74	2.83	2.81	3.33	2.43	2.04	38.44
1899	2.94	5.57	5.93	1.73	4.16	3.07	6.13	5.81	4.09	3.05	1.26	1.97	45.71
1900	2.95	4.54	2.74	2.50	1.69	6.49	4.14	2.42	3.67	2.82	4.87	2.88	41.71
1901	2.68	.70	3.99	5.00	5.12	2.81	3.64	7.13	3.45	2.71	2.48	6.15	45.86

RICHMOND, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.08	3.64	3.81	3.71	3.90	3.32	4.62	5.15	4.16	3.41	2.53	3.40	44.73
1896	1.05	1.05	3.78	4.83	5.28	2.98	4.15	6.31	2.38	4.59	2.22	3.08	41.65
1899	2.94	4.72	5.56	2.04	2.14	2.41	4.12	5.61	6.21	4.03	1.19	2.33	43.30
1900	2.71	4.42	2.89	3.62	2.20	3.08	3.13	3.66	4.08	2.55	2.87	2.60	37.76
1901	2.80	.55	3.79	5.29	3.80	2.32	5.06	6.99	3.21	.79	1.37	6.08	42.05

SALEM, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.94	3.88	3.75	2.98	4.34	3.67	4.09	4.59	3.87	3.07	1.94	2.96	42.08
1896	2.82	4.37	5.77	2.46	2.01	4.79	6.53	1.41	4.92	.53	5.16	.41	41.18
1897	1.69	7.56	3.73	1.56	4.03	1.31	3.64	1.76	2.56	4.17	1.25	3.82	37.08
1898	2.95	.58	3.35	1.99	6.74	2.82	5.06	4.14	3.66	8.63	1.50	2.58	44.00
1899	3.37	6.09	5.87	2.59	2.35	3.27	3.46	4.44	4.44	2.08	1.24	2.13	41.33
1900	3.73	4.03	4.80	2.89	3.12	4.20	2.41	.33	5.43	5.18	(1.94)	(2.96)	41.02
1901	2.20	.76	3.43	6.31	8.21	7.35	6.02	10.90	3.59	.71	1.07	6.71	57.26

STANARDSVILLE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.32	3.11	3.64	3.02	4.61	3.38	4.57	4.63	3.72	3.58	2.39	2.82	42.79
1896	2.41	4.79	2.74	1.83	3.73	3.13	7.41	2.97	5.41	.11	5.34	T.	39.87
1897	1.88	5.08	2.51	1.86	4.45	3.51	7.70	2.27	.65	3.81	2.68	4.40	40.80
1898	2.49	.65	4.52	3.24	5.72	2.51	5.22	6.06	8.11	12.01	2.46	4.20	52.19
1899	4.11	4.43	6.25	1.47	3.55	2.74	3.15	4.14	5.17	2.87	1.52	2.10	41.50
1900	3.88	3.56	(3.64)	2.77	1.13	5.87	2.08	.97	4.40	4.07	(2.39)	(3.10)	37.81
1901	1.62	T.	4.34	6.52	9.30	2.76	5.51	8.90	3.08	(3.58)	1.70	4.90	52.21

STAUNTON, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.61	2.98	3.40	2.91	4.55	3.98	3.29	3.55	3.84	2.97	2.33	2.66	38.92
1896	2.55	3.81	4.41	1.33	4.13	6.58	6.10	3.92	8.06	.23	5.01	T.	46.15
1897	.92	3.99	2.56	1.56	5.75	2.18	3.70	2.30	.73	2.84	2.14	3.31	31.98
1898	2.89	.55	3.10	2.95	4.82	2.16	4.41	5.16	2.22	7.13	1.74	3.00	40.13
1899	3.46	4.89	6.15	1.56	3.64	1.39	1.33	5.46	3.89	3.06	.90	1.14	38.87
1900	3.01	3.38	3.45	2.27	3.19	5.66	2.57	2.34	3.64	4.58	2.88	2.05	39.02
1901	2.29	.32	3.39	8.42	7.88	4.97	5.39	6.71	3.46	.51	1.40	6.44	51.18

Depth of run-off, in inches, from the drainage basin of north (of James) River at Glasgow, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.63	3.99	2.32	1.19	2.83	0.62	0.51	0.31	0.23	0.28	0.32	0.72	13.95
1898	.99	.53	1.28	2.00	2.38	.80	.72	2.38	.41	2.48	1.23	1.39	16.59
1899	2.05	2.83	[a]4.44	1.03	.77	.30	.24	.28	.31	.24	.31	.33	13.13
1900	1.41	2.32	2.91	1.29	.82	1.36	.48	.31	.37	.56	1.03	1.22	14.08
1901	1.04	.43	2.44	4.20	2.77	3.00	1.18	2.49	.97	.55	.39	4.50	23.96
Average	1.22	2.12	2.68	1.94	1.91	1.22	.63	1.15	.46	.82	.68	1.63	16.34

[a] Approximate.

Depth of run-off, in inches, from the drainage basin of James River at Buchanan, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.48	3.75	1.90	0.88	1.86	0.52	0.54	0.36	0.23	0.23	0.20	0.54	11.49
1898	1.06	.55	1.29	1.93	1.98	.48	.47	1.84	.49	1.98	1.08	1.20	14.35
1899	1.83	3.03	4.53	1.68	1.99	1.05	.30	.26	.36	.21	.24	.38	15.86
1900	1.27	2.10	3.21	1.44	.66	1.17	.42	.23	.32	.84	2.01	1.65	15.32
1901	1.53	.62	2.12	4.65	3.30	3.06	1.45	2.62	.87	.40	.28	3.77	24.64
Average	1.23	2.01	2.61	2.12	1.96	1.25	.64	1.06	.45	.73	.76	1.51	16.33

Depth of run-off, in inches, from the drainage basin of James River at Cartersville, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	4.55	3.35	4.55	1.67	1.29	0.62	0.32	0.54	0.52	0.31	0.59	0.51	18.82
1900	1.53	1.96	2.55	1.81	.89	1.37	.47	.25	.30	.67	1.13	1.48	14.41
1901	1.71	.61	1.52	4.38	3.29	3.08	1.43	3.08	1.23	.69	.50	2.95	24.47
Average	2.60	1.97	2.87	2.62	1.82	1.69	.74	1.29	.68	.56	.74	1.65	19.23

Depth of run-off, in inches, from the drainage basin of Appomattox River at Mattoax, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	.....	.....	.....	.....	.....	.....	.....	.....	0.26	0.28	0.35	0.59	.....
1901	1.52	0.47	0.80	3.64	3.22	0.64	0.81	4.12	.67	.52	.47	2.26	19.61
Average	1.52	.47	.80	3.64	3.22	.64	.81	4.12	.67	.52	.47	2.26	19.61

Rainfall and run-off in James River Basin.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Ashland	42.86	36.15	42.89	43.34	45.21	37.45	49.85
Barbourville	43.61	42.10	38.78	43.96	41.53	38.05	57.26
Bedford City	41.69	44.53	31.68	47.96	44.85	42.35	55.50
Bonair	43.73	41.94	41.69	42.49	44.20	36.87	52.66
Buckingham	41.95	39.63	34.71	36.42	48.90	40.36	52.26
Christiansburg	37.47	39.36	36.74	38.00	42.60	46.01	.....
Clifton Forge	35.28	37.09	37.92	37.46	24.68	37.91	36.63
Dale Enterprise	42.62	34.73	32.99	50.38	31.99	37.52	56.29
Doswell	35.46	.....	32.59	37.82	37.58	27.56	41.75
Farmville	40.95	.....	34.83	44.22	47.16	39.75	39.02
Fredericksburg	40.66	35.48	39.82	42.88	47.88	41.95	45.38
Hot Springs	39.97	41.13	35.54	51.88	42.13	41.85	55.45
Lexington	40.69	44.52	37.06	47.06	41.41	40.30	44.40
Lynchburg	43.99	46.64	40.08	49.93	52.91	47.10	54.81
Petersburg	45.02	42.78	37.56	36.44	45.71	41.71	45.86
Richmond	44.73	.....	.....	41.65	43.30	37.76	42.05
Salem	42.08	41.18	37.08	44.00	41.33	41.02	57.26
Stanardsville	42.79	39.87	40.80	52.19	41.50	37.81	52.21
Staunton	38.92	46.15	31.98	40.13	36.87	39.02	51.18
Average	41.29	40.83	36.93	43.59	42.20	39.60	49.38
RUN-OFF.							
North (of James) at Glasgow	15.29	18.14	13.95	16.59	13.13	[a]14.08	23.96
James at Buchanan	11.68	10.77	11.49	14.35	15.86	15.32	24.64
James at Cartersville	.....	.....	.....	.....	18.82	14.41	24.47
Appomattox at Mattoax	.....	.....	.....	.....	.....	.....	19.61
Average run-off	13.49	14.46	12.72	15.47	15.94	14.60	23.17
Percentage of rainfall	32.67	35.42	34.44	35.49	37.75	36.87	46.93

[a] Approximate.

SOUTHERN ATLANTIC COAST DRAINAGE.

Systematic measurements of discharge of many of the larger rivers of the Southern Atlantic States have been made during the year. The drainage areas of the rivers in that region are in general similar. Most of the streams rise in the southern Appalachian Mountains or their foothills. In the upper part of their courses they are rapid, with considerable fall. Across the Piedmont Plain their valleys are wide and their flow in general is sluggish, with occasional falls over rocky beds. Many of them have falls that could be utilized for water power, and it is largely to that end that data of the flow are being collected. In the study of water power it is important to know the flow and the fall. The fall can readily be determined by an engineer, but the variations in flow often require long and careful study. Gaging stations, to determine the latter, have been established on nearly all of the larger streams in the region, and it is hoped that in the near future our information of their fall will be extended.

The stations maintained by the survey in previous years were kept up during 1901 on the following rivers: On Roanoke River and tributaries; on Cape Fear, Yadkin, and Catawba rivers; on Savannah River and tributaries; on Oconee River and tributaries, and on Ocmulgee River. New stations were established in Georgia during 1901 on Middle Oconee River near Athens; on Oconee River at Barnett Shoals; on Apalachee River near Buckhead; on Alcovy River near Covington; and on Ocmulgee River near Flovilla.

The results for the year 1901, where available, are given on the following pages. In addition to these so-called permanent stations, many temporary stations are being maintained on streams in the Southern Appalachian region, the results for which will be found in the water-supply papers on operations at river stations.

Storms of considerable magnitude and duration during May and June, 1901, were the cause of high floods on the rivers draining from the Appalachian region into the Atlantic and the Gulf of Mexico. The damage caused by the freshets on some of the rivers was very heavy, particularly along the Catawba and Yadkin rivers, and along Cane Creek and Elkhorn Creek, in McDowell County, W. Va. Although the precipitation in these instances was unusually great, the rapidity and the violence of the run-off must be attributed in no small measure to the partial deforestation that has taken place at the headwaters of these streams. The accompanying illustrations will furnish an idea of the nature of the havoc wrought in some localities.

ROANOKE RIVER.

Estimated monthly discharge of Staunton River at Randolph, Va.

[Drainage area, 3,076 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	8,625	1,120	1,878	0.61	0.68
October	17,900	1,350	2,597	.84	.97
November	13,100	2,025	2,938	.96	1.07
December	18,600	2,550	3,944	1.28	1.48
1901.					
January	35,980	2,550	5,362	1.74	2.01
February	3,860	2,410	2,948	.98	1.02
March	14,850	2,340	4,000	1.30	1.50
April	36,910	3,580	9,620	3.13	3.49
May	37,940	2,980	8,148	2.65	3.16
June	9,750	3,140	4,759	1.55	1.73
July	30,980	2,690	6,259	2.03	2.34
August	45,100	2,620	13,185	4.29	4.94
September	6,955	2,620	3,998	1.30	1.45
October	6,725	2,795	3,346	1.09	1.26
November	5,260	2,725	2,984	.97	1.08
December	75,100	2,830	9,621	3.13	3.61
The year	75,100	2,340	6,186	2.01	27.59

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 239; rating table on page 319 of same paper.

Estimated monthly discharge of Dan River at South Boston, Va.

[Drainage area, 2,750 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	7,605	700	1,430	0.52	0.58
October	6,500	1,200	1,842	.67	.77
November	4,600	1,360	1,804	.66	.74
December	15,100	2,075	2,785	1.01	1.16

Estimated monthly discharge of Dan River at South Boston, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,965	1,860	3,387	1.23	1.42
February	2,675	1,600	2,042	.74	.77
March	25,000	1,600	3,504	1.27	1.46
April	38,800	2,375	6,382	2.32	2.59
May	45,600	2,300	7,297	2.65	3.06
June	3,100	1,925	2,292	.83	.93
July	44,200	2,150	6,132	2.23	2.58
August	36,600	1,860	9,866	3.59	4.14
September	5,100	2,150	2,902	1.06	1.18
October	4,100	1,860	2,353	.86	.99
November	3,730	1,730	2,032	.74	.83
December	51,200	2,000	6,875	2.50	2.89
The year	51,200	1,600	4,589	1.67	22.84

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 240; rating table on page 319 of same paper.

Estimated monthly discharge of Roanoke River at Roanoke, Va.

[Drainage area, 388 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,367	187	522	1.35	1.56
February	374	140	245	.63	.66
March	3,233	170	559	1.44	1.66
April	8,924	429	1,837	4.73	5.27
May	17,016	349	2,396	6.18	7.13
June	2,094	429	940	2.42	2.70
July	4,372	205	924	2.38	2.75
August	18,104	240	2,098	5.41	6.23
September	1,156	260	435	1.12	1.25
October	723	205	277	.71	.82
November	280	170	199	.51	.57
December	15,044	170	1,488	3.84	4.43
The year	18,104	140	993	2.56	35.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 241; rating table on page 319 of same paper.

Estimated monthly discharge of Roanoke River at Neal, N. C.

[Drainage area, 8,717 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,125	4,190	10,053	1.15	1.33
February	7,700	3,630	5,186	.59	.61
March	41,550	3,420	9,370	1.07	1.23
April	56,960	11,070	24,914	2.86	3.19
May	85,200	4,980	20,817	2.39	2.76
June	27,640	5,240	11,138	1.28	1.43
July	51,055	5,205	15,898	1.82	2.10
August	57,300	4,190	30,897	3.54	4.08
September	30,550	5,130	10,919	1.25	1.39
October	13,380	4,190	6,563	.75	.86
November	8,305	3,980	4,637	.53	.59
December	52,535	4,400	14,865	1.70	1.96
The year	85,200	3,420	13,763	1.58	21.53

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 242; rating table on page 320 of same paper.

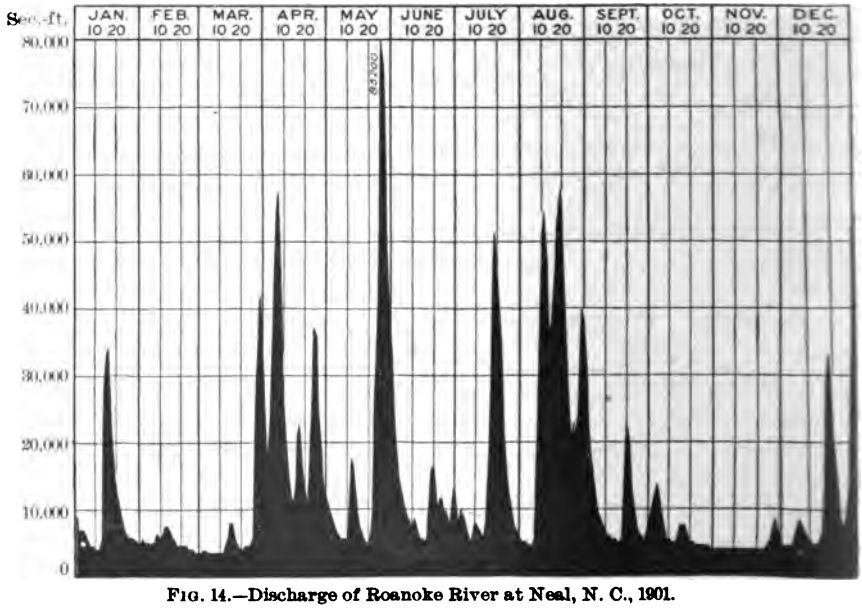


FIG. 14.—Discharge of Roanoke River at Neal, N. C., 1901.

CAPE FEAR RIVER.

Estimated monthly discharge of Deep River at Cumnock, N. C.

[Drainage area, 1,110 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
July (18 days)			274	0.25	0.17
August	394	72	138	.12	.14
September	3,990	116	308	.28	.31
October	274	80	139	.12	.14
November	4,550	106	368	.33	.37
December	5,190	126	878	.79	.91
1901.					
January	4,830	250	827	.75	.86
February	2,990	262	656	.59	.61
March	27,100	181	3,564	3.21	3.70
April	9,075	95	1,958	1.76	1.96
May	6,820	80	989	.89	1.03
June	9,918	334	2,129	1.92	2.14
July	13,540	322	2,500	2.25	2.60
August	14,135	322	4,179	3.76	4.34
September	10,950	298	1,805	1.63	1.82
October	1,125	322	434	.39	.45
November	334	250	286	.26	.29
December	16,696	274	1,824	1.64	1.89
The year	27,100	80	1,763	1.59	21.69

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 243; rating table on page 320 of same paper.

Estimated monthly discharge of Cape Fear River at Fayetteville, N. C.

[Drainage area, 4,498 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	7,120	1,600	3,048	0.68	0.78
February	4,850	1,560	2,659	.59	.61
March	28,050	1,200	4,209	.94	1.08
April	49,065	2,440	9,624	2.14	2.39
May	71,625	1,560	11,502	2.56	2.95
June	11,800	1,760	4,352	.97	1.08
July	37,675	1,520	8,072	1.80	2.08
August	43,450	1,440	13,965	3.11	3.59
September	41,350	1,600	7,296	1.62	1.81
October	4,450	1,400	2,342	.52	.60
November	2,440	1,400	1,555	.35	.39
December	27,200	1,440	3,828	.85	.98
The year	71,625	1,200	6,038	1.34	18.34

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 244; rating table on page 320 of same paper.

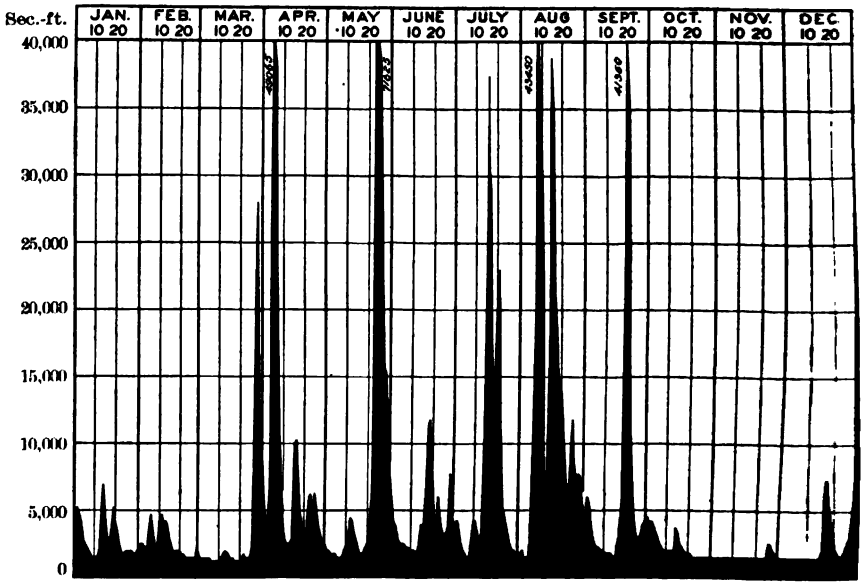


FIG. 15.—Discharge of Cape Fear River at Fayetteville, N. C., 1901.

A. WHEAT FIELD WASHED OUT AND COVERED WITH SAND BY FLOOD ON YADKIN RIVER NEAR ELKIN, N C.

B. PLATE-GIRDER BRIDGE ON ELKHORN CREEK AT NORWOOD, W. VA., DEMOLISHED BY FLOOD.

YADKIN RIVER.

Estimated monthly discharge of Yadkin River at Salisbury, N. C.

[Drainage area, 3,399 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	31,180	2,925	5,284	1.55	1.79
February	6,195	2,420	3,507	1.03	1.07
March	37,780	2,585	5,922	1.74	2.01
April	81,030	4,180	13,787	4.06	4.53
May	70,870	4,000	11,152	3.28	3.78
June	32,220	4,540	10,950	3.22	3.59
July	29,200	3,820	8,455	2.49	2.87
August	44,132	3,640	16,509	4.86	5.60
September	16,120	4,360	6,764	1.99	2.22
October	13,420	3,640	5,116	1.51	1.74
November	6,380	3,100	3,683	1.08	1.20
December	104,640	3,280	12,506	3.68	4.24
The year	104,640	2,420	8,636	2.54	34.64

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 246; rating table on page 320 of same paper.

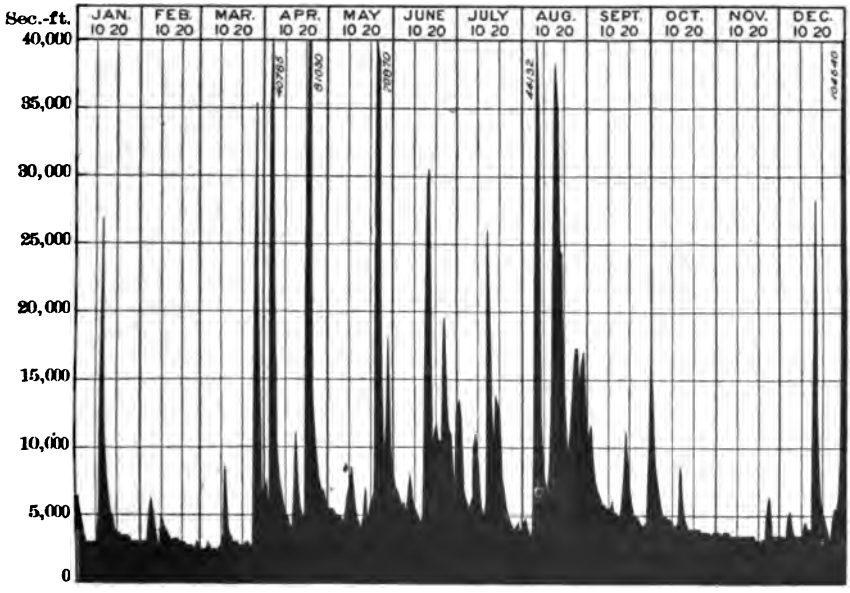


FIG. 16.—Discharge of Yadkin River at Salisbury, N. C., 1901.

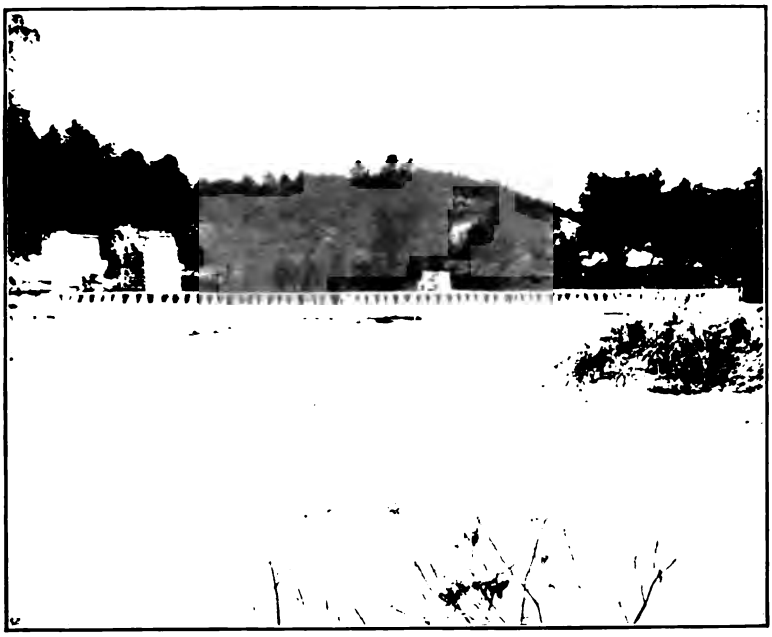
CATAWBA RIVER.

Estimated monthly discharge of Catawba River at Catawba, N. C.

[Drainage area, 1,514 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	17,240	2,720	3,777	2.49	2.87
February	4,175	2,720	3,009	1.99	2.07
March	38,375	2,855	5,130	3.39	3.91
April 1-20			9,911	6.55	4.87
May	81,500	3,150	8,260	5.46	6.29
June	24,540	2,810	5,358	3.54	3.95
July	6,655	2,275	3,383	2.23	2.57
August	40,250	2,450	10,326	6.82	7.87
September	6,590	2,495	3,493	2.31	2.58
October	4,120	2,315	2,601	1.72	1.98
November	3,500	2,000	2,311	1.53	1.71
December	45,875	2,090	5,830	3.85	4.44

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 247; rating table on page 320 of same paper.



A CATAWBA RIVER NEAR MORGANTON, N. C., AT SITE OF STEEL HIGHWAY BRIDGE DESTROYED BY FLOOD.

B. CATAWBA RIVER AT CATAWBA, N. C., SHOWING BANKS WASHED OUT BY FLOOD.

Estimated monthly discharge of Catawba River near Rockhill, S. C.

[Drainage area, 2,987 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	26,500	3,825	5,245	1.76	2.03
February	7,750	3,665	4,240	1.42	1.48
March	57,250	3,505	7,219	2.42	2.79
April	107,850	4,625	15,812	5.29	5.90
May	127,850	4,145	14,302	4.79	5.52
June	30,000	4,625	9,211	3.08	3.44
July	20,400	3,825	6,159	2.06	2.37
August	64,125	3,825	18,983	6.36	7.34
September	14,850	4,850	7,130	2.39	2.67
October	8,550	4,145	4,980	1.67	1.93
November	4,545	3,985	4,121	1.38	1.54
December	98,850	3,825	13,775	4.61	5.31
The year	127,850	3,505	9,265	3.10	42.32

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 248; rating table on page 320 of same paper.

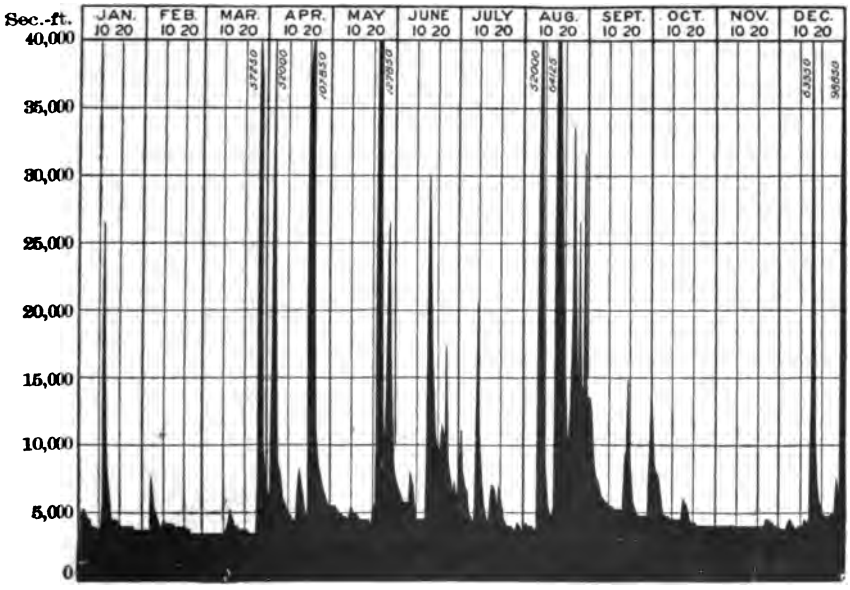


FIG. 17.—Discharge of Catawba River near Rockhill, S. C., 1901.

BROAD RIVER (OF THE CAROLINAS).

Estimated monthly discharge of Broad River (of the Carolinas) near Alston, S. C.

[Drainage area, 4,609 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	23,550	4,105	7,227	1.57	1.81
February	32,100	3,816	7,775	1.69	1.76
March	100,987	3,340	11,784	2.56	2.95
April	103,300	5,075	22,490	4.88	5.44
May	131,050	3,765	15,331	3.33	3.84
June	54,675	4,540	13,666	2.96	3.30
July	13,350	4,450	6,349	1.38	1.59
August	104,225	3,765	30,201	6.55	7.55
September	89,425	6,750	18,113	3.93	4.38
October	14,850	5,075	7,123	1.55	1.79
November	6,960	4,360	4,892	1.07	1.18
December	121,337	4,450	16,457	3.57	4.12
The year	131,050	3,340	13,451	2.92	39.71

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 250; rating table on page 320 of same paper.

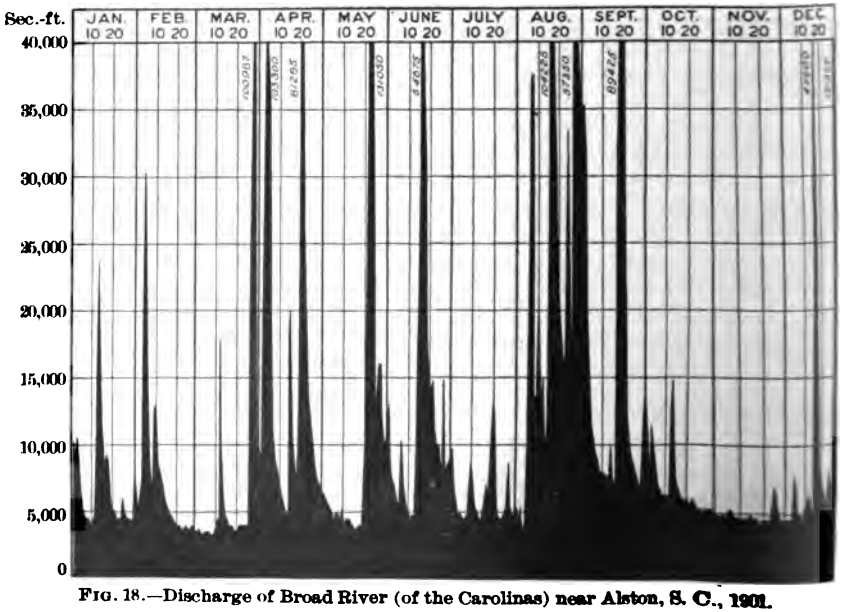


FIG. 18.—Discharge of Broad River (of the Carolinas) near Alston, S. C., 1901.

SALUDA RIVER.

Estimated monthly discharge of Saluda River at Waterloo, S. C.

[Drainage area, 1,056 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,670	780	1,834	1.74	2.01
February	7,166	672	2,066	1.96	2.04
March	10,668	843	2,203	2.09	2.41
April	11,212	1,046	3,382	3.20	3.57
May	10,906	650	2,539	2.40	2.77
June	12,810	1,114	3,136	2.97	3.31
July	2,474	750	1,491	1.41	1.63
August	12,028	430	4,949	4.69	5.41
September	12,878	1,556	3,795	3.59	4.01
October	3,732	1,148	1,862	1.76	2.03
November	1,964	526	1,261	1.19	1.33
December	12,368	526	2,709	2.57	2.96
The year	12,878	430	2,602	2.46	33.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 250; rating table on page 320 of same paper.

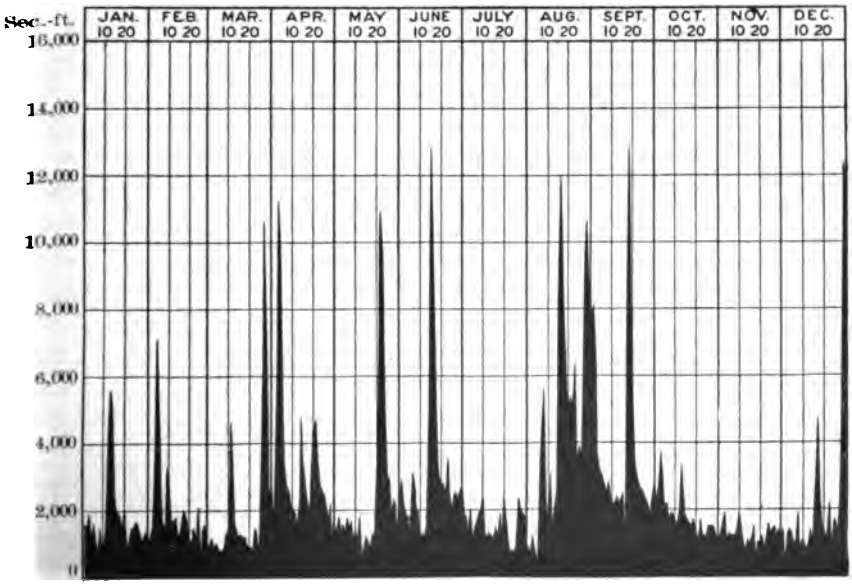


FIG. 19.—Discharge of Saluda River at Waterloo, S. C., 1901.

SAVANNAH RIVER.

Estimated monthly discharge of Tallulah River at Tallulah Falls, Ga.

[Drainage area, 191 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January			[a] 810	4.24	4.89
February	1,365	587	687	3.60	3.75
March	4,550	461	976	5.11	5.89
April	3,850	770	1,424	7.46	8.32
May	5,250	540	1,065	5.58	6.43
June	1,050	540	817	4.28	4.78
July	875	429	625	3.27	3.77
August	4,690	391	1,608	8.42	9.71
September	2,030	640	1,358	7.11	7.93
October	613	429	511	2.68	3.09
November	429	391	398	2.08	2.32
December	6,650	391	1,013	5.30	6.11
The year	6,650	391	941	4.93	66.99

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 251; rating table on page 320 of same paper.

Estimated monthly discharge of Tugaloo River near Madison, S. C.

[Drainage area, 593 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	8,780	1,180	2,153	3.63	4.19
February	4,380	1,180	1,719	2.90	3.02
March	15,540	1,135	2,444	4.12	4.75
April	16,460	2,060	3,804	6.42	7.16
May	12,540	1,475	2,932	4.95	5.71
June	6,140	1,475	2,549	4.30	4.80
July	2,300	1,180	1,570	2.65	3.06
August	13,660	1,045	4,876	8.22	9.48
September	6,620	1,860	3,047	5.14	5.74
October	2,060	1,225	1,542	2.60	3.00
November	1,225	960	1,091	1.84	2.05
December	14,860	960	2,577	4.35	5.01
The year	16,460	960	2,525	4.26	57.97

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 252; rating table on page 320 of same paper.

Estimated monthly discharge of Savannah River near Calhoun Falls, S. C.

[Drainage area, 2,712 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	16,950	4,335	7,113	2.62	3.02
February	19,560	3,150	5,817	2.14	2.23
March	62,625	2,690	9,040	3.33	3.84
April	40,875	7,380	13,006	4.80	5.35
May	35,220	3,900	8,895	3.28	3.78
June	47,400	5,640	11,193	4.13	4.61
July	8,250	2,910	4,800	1.77	2.04
August	48,705	2,910	15,328	5.65	6.51
September	65,670	3,500	10,066	3.71	4.14
October	5,640	2,280	3,578	1.32	1.52
November	2,280	1,660	1,911	.70	.78
December	68,715	1,870	10,411	3.84	4.43
The year	68,715	1,660	8,430	3.10	42.25

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 253; rating table on page 320 of same paper.

Estimated monthly discharge of Savannah River at Augusta, Ga.

[Drainage area, 7,294 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	48,590	7,680	14,295	1.96	2.26
February	75,060	7,440	16,566	2.27	2.36
March	86,400	6,500	15,133	2.07	2.39
April	111,920	10,460	25,365	3.48	3.88
May	77,600	7,280	15,344	2.10	2.42
June	76,720	8,400	19,574	2.68	2.99
July	16,430	6,350	8,981	1.23	1.42
August	92,560	5,600	26,256	3.60	4.15
September	111,920	8,740	20,568	2.82	3.15
October	14,200	7,120	9,172	1.26	1.45
November	7,920	7,120	7,547	1.03	1.15
December	107,520	7,120	18,565	2.54	2.93
The year	111,920	5,600	16,447	2.25	30.55

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 254; rating table on page 320 of same paper.

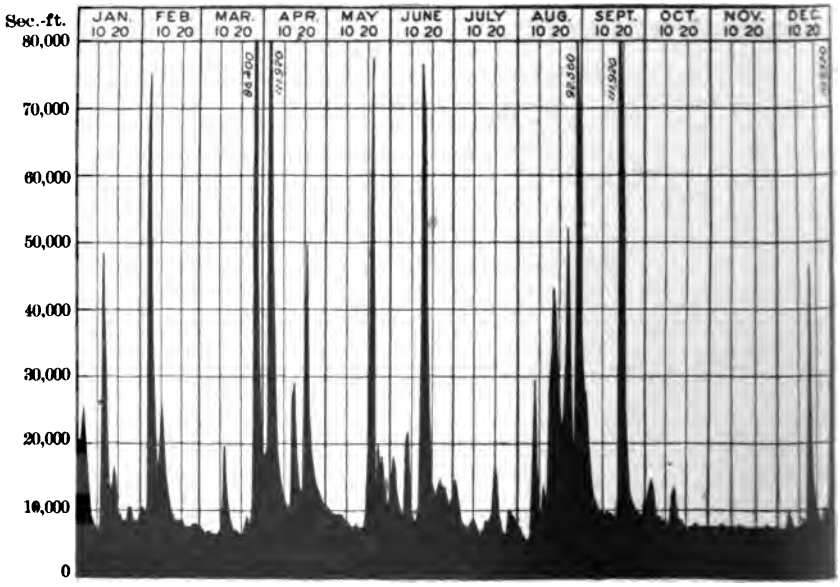


FIG. 20.—Discharge of Savannah River at Augusta, Ga., 1901.

Estimated monthly discharge of Broad River (of Georgia) near Carlton, Ga.

[Drainage area, 762 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	11,575	940	2,093	2.75	3.17
February	6,715	1,010	1,697	2.23	2.32
March	15,288	870	2,266	2.97	3.42
April	12,182	1,080	2,421	3.18	3.55
May	6,715	870	1,673	2.20	2.54
June	11,170	1,010	2,354	3.09	3.44
July	4,550	800	1,270	1.67	1.93
August	9,550	730	3,196	4.19	4.83
September	16,030	1,010	2,153	2.82	3.14
October	2,750	870	1,083	1.42	1.64
November	1,010	870	898	1.18	1.32
December	22,915	870	2,769	3.63	4.18
The year	22,915	730	1,989	2.61	35.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 255; rating table on page 321 of same paper.

ALTAMAHA RIVER.

Estimated monthly discharge of Middle Oconee River near Athens, Ga.

[Drainage area, 395 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
November	572	430	486	1.23	1.37
December	12,900	464	1,373	3.48	4.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 257; rating table on page 321 of same paper.

Estimated monthly discharge of Oconee River at Barnett Shoals, Ga.

[Drainage area, 835 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
August 13–31			4,092	4.90	3.46
September	9,542	824	1,763	2.11	2.35
October	1,958	780	916	1.10	1.27
November	918	780	801	.96	1.07
December	16,410	780	2,294	2.75	3.17

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 257; rating table on page 321 of same paper.

Estimated monthly discharge of Apalachee River near Buckhead, Ga.

[Drainage area, 440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
March	2,972	470	847	1.92	2.21
April	3,660	552	1,123	2.55	2.84
May	1,680	388	553	1.26	1.45
June	2,147	552	910	2.07	2.31
July	1,460	333	582	1.32	1.52
August	2,697	305	896	2.04	2.35
September	3,247	305	711	1.62	1.81
October	525	280	349	.79	.91
November	415	280	326	.74	.83
December	5,772	333	1,027	2.33	2.69

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 258; rating table on page 321 of same paper.

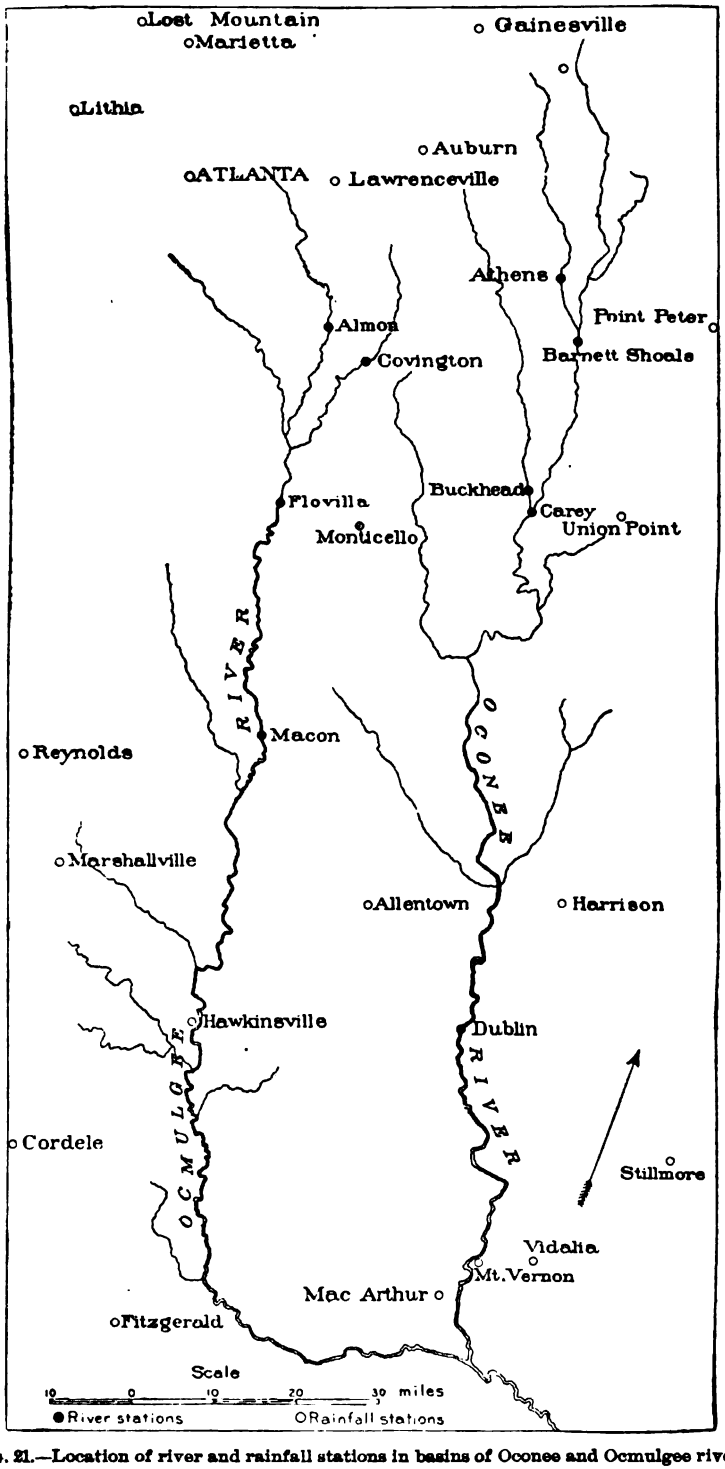


FIG. 21.—Location of river and rainfall stations in basins of Oconee and Ocmulgee rivers

Estimated monthly discharge of Oconee River near Dublin, Ga.

[Drainage area, 4,182 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	15,706	5,105	9,396	2.25	2.60
February	17,872	4,670	9,315	2.23	2.32
March	18,670	3,490	6,494	1.55	1.79
April	25,624	4,287	12,344	2.95	3.29
May	9,094	2,742	4,250	1.02	1.18
June	12,856	4,199	8,065	1.93	2.15
July	7,270	2,559	4,258	1.02	1.18
August	11,602	2,080	5,999	1.43	1.65
September	21,976	2,125	8,035	1.92	2.14
October	5,674	2,173	3,046	.73	.84
November	2,742	2,223	2,369	.56	.62
December	9,664	2,329	4,435	1.06	1.22
The year	25,624	2,080	6,500	1.55	20.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 259; rating table on page 321 of same paper.

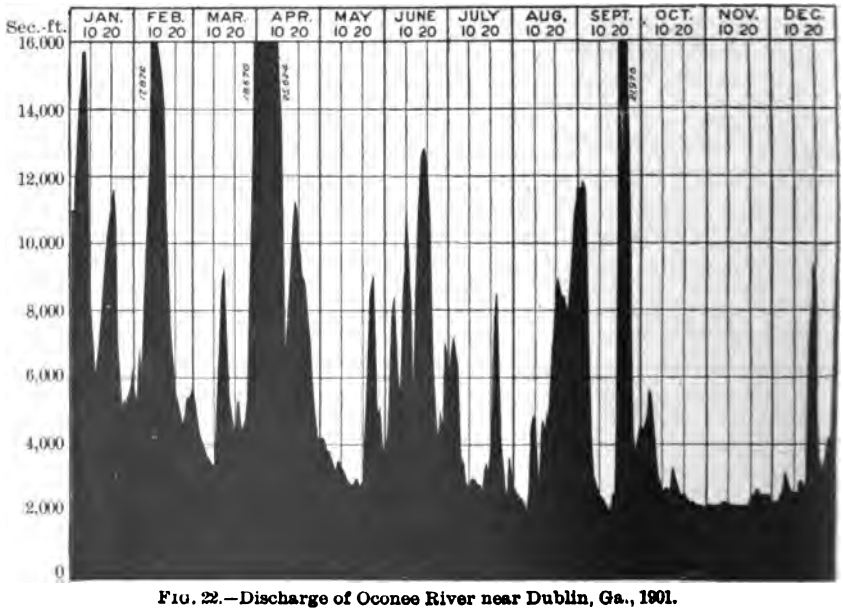


FIG. 22.—Discharge of Oconee River near Dublin, Ga., 1901.

Estimated monthly discharge of Alcovy River near Covington, Ga.

[Drainage area, 228 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May	593	162	271	1.19	1.37
June	821	198	442	1.94	2.16
July	840	143	377	1.65	1.90
August	1,030	111	582	2.55	2.94
September	935	152	361	1.58	1.76
October	555	152	228	1.00	1.15
November	273	162	183	.80	.89
December	1,144	162	393	1.72	1.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 260; rating table on page 321 of same paper.

Estimated monthly discharge of Yellow River at Almon, Ga.

[Drainage area, 379 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,070	511	934	2.46	2.84
February	5,020	455	1,076	2.84	2.96
March	3,070	361	710	1.87	2.16
April	4,591	482	1,221	3.22	2.59
May	2,095	320	551	1.45	1.67
June	1,900	406	741	1.96	2.19
July	3,070	250	488	1.29	1.49
August	3,070	235	988	2.61	3.01
September	3,070	361	655	1.73	1.93
October	925	266	397	1.05	1.21
November	406	250	320	.84	.94
December	6,970	283	880	2.32	2.68
The year	6,970	235	947	1.97	25.67

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No 65, page 261; rating table on page 321 of same paper.

Estimated monthly discharge of Ocmulgee River near Flovilla, Ga.

[Drainage area, 1,500 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
August	7,987	835	2,916	1.94	2.24
September	8,451	1,037	2,219	1.48	1.65
October	2,837	907	1,223	.82	.94
November	1,138	907	1,593	1.06	1.18
December	11,850	907	2,531	1.69	1.95

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 262; rating table on page 321 of same paper.

Estimated monthly discharge of Towaliga River near Juliette, Ga.

[Drainage area, 350 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,173	327	602	1.72	1.98
February	1,461	345	576	1.65	1.72
March	1,965	309	520	1.49	1.72
April	2,379	363	707	2.02	2.25
May	1,245	255	380	1.09	1.26
June	885	237	440	1.26	1.41
July	1,533	144	337	.96	1.11
August	1,893	154	531	1.52	1.75
September	1,245	154	360	1.03	1.15
October	417	165	209	.60	.69
November	309	154	185	.53	.59
December	1,857	190	475	1.36	1.57
The year	2,379	144	444	1.27	17.20

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 264; rating table on page 321 of same paper.

Estimated monthly discharge of Ocmulgee River at Macon, Ga.

[Drainage area, 2,425 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	13,010	2,244	4,908	2.02	2.33
February	21,880	2,185	5,165	2.13	2.22
March	22,720	1,693	4,586	1.89	2.18
April	34,060	2,244	6,556	2.70	3.01
May	13,590	1,546	2,806	1.16	1.34
June	6,704	1,693	3,323	1.37	1.53
July	19,780	1,314	2,521	1.04	1.20
August	16,420	1,184	4,686	1.93	2.23
September	29,440	1,227	3,913	1.61	1.80
October	3,081	978	1,412	.58	.67
November	1,314	978	1,104	.46	.51
December	30,280	1,059	4,324	1.78	2.05
The year	34,060	978	3,775	1.56	21.07

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 265; rating table on page 321 of same paper.

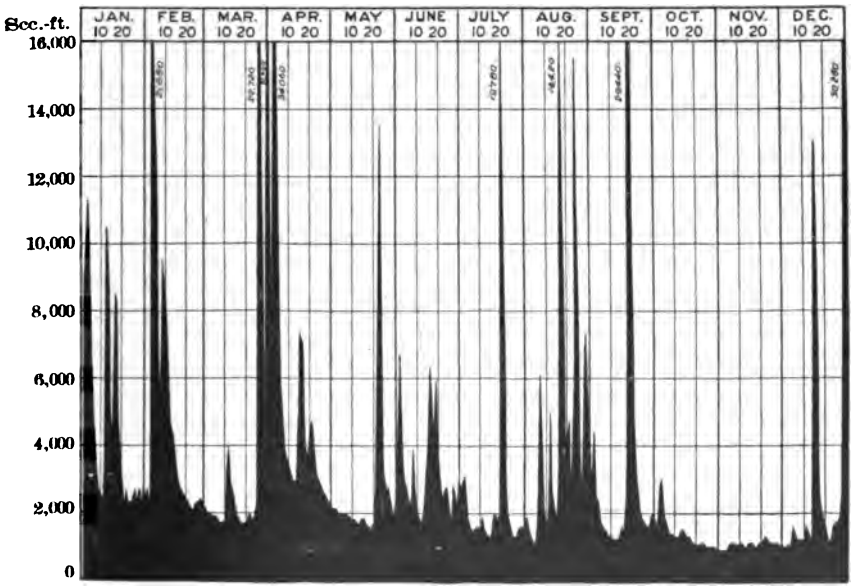


FIG. 23.—Discharge of Ocmulgee River at Macon, Ga., 1901.

PRECIPITATION IN THE BASINS OF OCONEE AND OCMULGEE RIVERS.

The principal observations of rainfall made within the Oconee and Ocmulgee river basins, considered here in conjunction, the two rivers being the principal tributaries of the Altamaha, are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 21, in connection with the points of river measurements which are located at Athens, Almon, Covington, Flovilla, Juliette, Macon, Barnett Shoals, Buckhead, Carey, and Dublin.

Location of rainfall stations in Oconee and Ocmulgee basins.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Atlanta	Fulton	Georgia	33 45	84 23	1,050	28-32
Athens	Clarke	do	33 58	83 23	850	21-27
Allentown	Wilkinson	do				5-6
Covington	Newton	do	33 37	83 49	748	8-12
Gillsville	Hall	do	34 13	83 56	1,052	11-13
Gainesville	do	do	34 16	83 47	1,227	15-29
Macon	Bibb	do	32 50	83 38	334	17-32
Marshallville	Macon	do				9-11
Point Peter	Oglethorpe	do	33 57	82 59	1,000	12-13

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1900, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers.

ATLANTA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	5.13	5.27	5.47	4.14	3.57	4.03	4.67	4.49	3.80	2.32	3.62	4.73	51.24
1896	3.12	3.04	3.29	.58	1.95	2.66	7.55	1.97	1.36	1.28	5.90	1.42	34.12
1897	3.48	4.59	5.74	5.06	.34	2.07	4.74	6.01	.14	1.80	2.29	3.00	39.26
1898	2.99	.62	4.09	5.15	1.35	.89	10.22	6.66	6.33	5.06	3.36	3.84	50.56
1899	3.69	6.62	5.38	1.71	1.21	1.46	6.42	3.15	2.27	3.71	2.65	4.15	42.42
1900	2.32	9.58	5.69	6.27	2.94	8.96	4.51	1.79	3.62	2.79	3.62	6.74	58.83
1901	5.95	4.04	5.71	5.27	7.55	3.10	5.37	9.83	3.76	.59	.99	7.61	59.77

ATHENS.

Normal	5.78	5.30	5.34	3.92	3.78	4.89	4.87	5.14	3.67	2.60	2.99	3.98	52.26
1896	(5.78)	(5.30)	(5.34)	(3.92)	1.78	3.93	10.31	1.00	.66	1.82	(2.99)	(3.98)	46.81
1897	(5.78)	(5.30)	(5.34)	(3.92)	.61	2.85	3.19	4.17	.64	3.12	1.10	2.83	38.85
1898	2.93	.66	3.55	5.58	2.48	1.53	5.43	5.73	6.36	7.40	3.85	3.81	49.31
1899	7.21	8.56	4.88	1.98	.83	1.55	2.50	3.93	1.45	3.59	1.35	2.78	40.61
1900	2.10	8.45	6.54	7.76	2.97	11.39	4.13	1.27	3.89	4.80	3.74	5.68	62.72
1901	4.14	3.57	4.78	5.59	4.90	6.53	3.51	17.87	3.30	1.05	.77	5.42	61.43

A. MONONGAHELA RIVER AT MORGANTOWN, W. VA

B. CHEAT RIVER, LOOKING UPSTREAM FROM CAMP EDEN, MONONGALIA COUNTY, W. VA.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers—Continued.

ALLENTOWN.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.23	6.70	4.74	3.94	2.08	3.13	5.26	5.08	3.55	3.86	4.01	4.21	49.74
1896	(3.23)	(6.70)	2.99	1.60	2.34	2.76	5.71	3.79	2.74	.72	7.49	5.21	45.28
1897	1.92	8.31	9.58	4.16	2.82	1.97	5.38	3.04	.73	2.51	.95	1.86	43.23
1898	1.48	1.02	1.13	7.22	.98	2.29	6.66	7.35	4.99	8.24	6.44	2.99	50.74
1899	6.38	9.32	3.13	3.15	1.72	1.69	3.50	3.26	.40	7.12	1.52	2.86	44.05
1900	2.42	10.26	5.57	4.10	2.59	6.96	6.08	3.11	1.90	3.61	6.61	8.06	61.22
1901	3.96	4.59	6.07	3.41	(2.08)	(3.13)	4.28	9.68	10.54	.97	1.03	4.26	53.95

COVINGTON.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	4.44	5.02	4.96	4.94	2.79	4.04	4.96	6.09	2.69	3.08	2.81	4.33	50.10
1896	4.59	2.67	2.95	2.94	1.88	3.71	7.24	3.16	.90	2.62	9.78	1.11	43.55
1897	2.51	6.27	7.58	4.29	.95	2.68	3.52	5.44	.98	2.98	1.32	3.07	41.59
1898	3.86	1.06	3.59	5.98	1.98	1.46	10.20	10.69	5.33	9.55	4.04	4.85	62.54
1899	8.06	8.38	3.71	2.66	3.26	2.16	2.66	2.96	1.54	4.62	2.46	3.14	45.61
1900	2.35	10.46	3.40	7.54	2.21	14.78	4.08	5.16	4.08	1.90	3.69	7.66	67.31
1901	3.89	3.95	6.56	4.32	5.99	4.28	3.34	10.75	4.49	.61	.50	7.83	56.51

GILLSVILLE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	4.47	5.08	5.39	3.94	3.26	4.14	5.88	5.13	4.17	2.44	2.54	3.26	49.70
1896	4.45	2.14	2.11	.80	4.68	2.82	7.62	1.48	1.48	1.57	6.13	.40	35.68
1897	4.26	5.40	6.50	6.62	.00	2.48	10.94	2.95	[a].00	5.11	1.83	3.91	50.00
1898	1.26	.36	3.54	4.20	1.03	2.64	6.75	7.78	10.18	8.18	3.17	3.54	52.58
1899	4.28	8.87	8.68	2.32	2.35	1.94	2.92	3.48	.53	2.37	2.80	3.61	44.10
1900	3.42	10.77	5.72	8.10	2.94	8.82	3.42	1.36	3.04	4.07	3.25	3.20	58.11
1901	6.44	3.43	6.50	6.20	6.11	5.89	5.57	11.73	5.38	.62	.10	6.14	64.11

GAINESVILLE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	5.96	6.34	6.78	4.30	3.39	4.67	5.04	6.03	3.99	2.74	3.71	5.24	58.19
1896	(5.96)	(6.34)	(6.78)	(4.30)	1.53	2.08	10.61	.77	1.62	(2.74)	6.77	2.02	51.52
1897	4.40	4.89	6.90	(4.30)	1.15	3.03	14.43	2.48	.05	2.67	3.46	2.78	50.54
1898	3.24	.79	4.41	5.29	1.03	1.23	12.12	9.58	6.71	7.30	3.58	3.37	58.65
1899	4.11	8.17	10.46	3.76	1.46	3.41	2.40	4.10	.40	2.43	2.82	4.49	48.01
1900	2.97	8.84	6.75	5.76	1.31	12.09	3.88	1.34	1.49	2.66	3.16	(5.24)	55.49
1901	8.02	3.53	6.69	5.84	6.35	6.89	5.47	13.58	4.65	1.24	.15	6.37	68.78

MACON.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.83	4.50	5.82	3.94	3.03	4.23	4.78	4.89	2.68	2.10	3.03	4.45	47.28
1896	3.58	5.85	3.47	1.73	1.82	3.29	6.16	5.66	.68	1.58	7.09	5.01	45.92
1897	1.95	8.33	10.58	3.30	.87	6.16	5.10	3.37	1.12	.70	(3.03)	(4.45)	48.96
1898	(3.83)	(4.50)	(5.82)	(3.94)	.45	2.63	6.15	8.76	4.17	6.60	(3.03)	(4.45)	54.33
1899	(3.83)	(4.50)	(5.82)	[a]3.11	1.83	1.61	2.47	1.94	1.61	5.20	1.73	3.45	37.10
1900	1.87	7.64	3.68	4.80	2.97	6.69	3.26	5.93	1.25	1.27	4.53	5.89	49.78
1901	3.53	3.91	6.94	3.86	2.85	3.82	1.15	3.95	4.64	1.59	.42	5.37	42.08

[a] Approximate.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers—Continued.

MARSHALLVILLE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	4.22	6.23	5.75	4.17	2.36	3.72	5.62	5.19	2.45	3.08	2.95	4.28	50.02
1896	5.25	8.08	4.15	3.60	3.10	2.04	12.56	2.60	1.17	2.15	8.78	4.75	58.23
1897	1.93	8.85	10.06	5.57	.96	5.87	3.20	4.10	1.16	1.02	.70	2.83	46.25
1898	1.35	1.19	2.00	9.12	1.19	3.76	6.84	9.27	1.34	7.83	6.79	4.19	54.87
1899	6.22	6.50	2.91	4.99	1.46	.96	2.89	3.59	.72	8.24	1.59	2.87	42.94
1900	2.51	10.72	4.25	4.02	1.10	4.38	4.74	3.30	.44	2.68	4.20	8.66	51.00
1901	4.53	3.98	6.78	3.28	4.41	6.57	2.22	6.68	9.38	2.55	1.06	5.65	57.09

POINT PETER.

Normal	5.09	5.16	5.27	3.83	2.75	4.03	5.44	5.80	3.68	2.87	3.12	3.57	50.61
1896	5.40	4.60	3.35	2.90	2.55	1.45	8.65	1.10	1.25	2.35	6.60	[a]3.15	43.35
1897	4.06	6.50	5.68	6.51	.96	3.91	4.37	6.74	[a]2.05	2.21	3.00	3.05	49.04
1898	3.10	.70	4.25	5.38	.17	1.82	11.51	8.74	2.59	8.79	4.58	3.62	55.25
1899	7.25	8.19	5.00	1.99	.68	2.06	2.54	4.27	1.14	4.28	2.69	3.14	43.23
1900	1.85	8.34	4.54	6.27	3.47	12.71	6.90	.73	4.74	2.89	3.63	5.69	61.73
1901	4.08	3.68	5.12	5.12	6.22	4.18	2.84	15.67	7.35	.54	.87	6.86	62.53

[a] Approximate.

Depth of run-off, in inches, from the drainage basin of Yellow River at Almon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	1.30	4.10	2.93	4.21	1.89	4.09	1.73	1.08	1.45	1.13	1.12	2.46	27.49
1901	2.84	2.96	2.16	2.59	1.67	2.19	1.49	3.01	1.93	1.21	.94	2.68	25.67
Average	2.07	3.53	2.54	3.40	1.78	3.14	1.61	2.04	1.69	1.17	1.03	2.57	26.57

Depth of run-off, in inches, from the drainage basin of Middle Oconee River at Athens.

Year.	Nov.	Dec.
1901	1.37	4.01

Depth of run-off, in inches, from the drainage basin of Apalachee River at Buckhead.

Year.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	2.21	2.84	1.45	2.31	1.52	2.35	1.81	0.91	0.83	2.69

Depth of run-off, in inches, from the drainage basin of Oconee River at Barnett Shoals.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	3.46	2.35	1.27	1.07	3.17

Depth of run-off, in inches, from the drainage basin of Alcovy River at Covington.

Year.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	1.37	2.16	1.90	2.94	1.76	1.15	0.89	1.98

Depth of run-off, in inches, from the drainage basin of Oconee River at Dublin.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1898	.....	.....	0.71	1.34	0.49	0.32	0.85	1.57	2.84	2.05	1.90	2.02	.....
1899	2.96	3.73	3.36	2.04	.94	.50	.46	.58	.44	.72	.45	.84	17.02
1900	.97	2.99	2.73	2.53	1.31	2.23	1.76	.63	.64	.61	.86	1.61	18.87
1901	2.60	2.32	1.79	3.29	1.18	2.15	1.18	1.65	2.14	.84	.62	1.22	20.98
Average	2.18	3.01	2.15	3.30	.98	1.30	1.06	1.11	1.52	1.06	.96	1.42	19.05

Depth of run-off, in inches, from the drainage basin of Ocmulgee River at Flovilla.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	2.24	1.65	0.94	1.18	1.95

Depth of run-off, in inches, from the drainage basin of Towaliga River at Juliette.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1901	1.98	1.72	1.72	2.25	1.26	1.41	1.11	1.75	1.15	0.69	0.59	1.57	17.20

Depth of run-off, in inches, from the drainage basin of Ocmulgee River at Macon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.64	1.83	4.22	2.51	0.81	0.79	0.91	0.84	0.32	0.30	0.36	0.51	14.04
1898	.62	.42	.60	1.20	.44	.30	.78	2.20	2.77	2.72	1.70	1.69	15.44
1899	2.66	3.50	2.62	2.06	1.00	.61	.56	.51	.40	.63	.46	.75	15.76
1900	.73	4.16	2.21	3.22	1.36	3.78	1.72	.95	1.18	.89	1.06	1.94	23.20
1901	2.33	2.22	2.18	3.01	1.34	1.53	1.20	2.23	1.80	.67	.51	2.05	21.07
Average	1.40	2.43	2.37	2.40	.99	1.40	1.03	1.35	1.29	1.04	.82	1.39	17.91

Depth of run-off, in inches, from the drainage basin of Oconee River at Carey.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	1.81	2.25	2.61	1.19	0.97	0.65	1.16	0.81	0.38	0.63	0.69	0.95	14.10
1898	1.15	.83	1.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	1.48	1.54	1.86	1.19	.97	.65	1.16	.81	.38	.63	.69	.95	12.31

Rainfall and run-off in Oconee and Ocmulgee basins.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Atlanta	51.24	34.12	39.26	50.56	42.42	58.83	59.77
Athens	52.26	46.81	38.85	49.31	40.61	62.72	61.43
Allentown	49.74	45.28	43.23	50.74	44.05	61.22	53.95
Covington	50.10	43.55	41.59	62.54	45.61	67.31	56.51
Gillsville	49.70	35.68	50.00	52.58	44.10	58.11	64.11
Gainesville	58.19	51.52	50.54	58.65	48.01	55.49	68.78
Macon	47.28	45.92	48.96	54.33	37.10	49.78	42.03
Marshallsville	50.02	58.23	46.25	54.87	42.94	51.00	57.09
Point Peter	50.61	43.35	49.04	55.25	43.23	61.75	62.53
Average	51.02	44.94	45.30	54.31	43.12	58.47	58.47
RUN-OFF.							
Almon	26.57	.....	.....	.....	.....	27.49	25.67
Dublin	19.05	.....	.....	.....	17.02	18.87	20.98
Juliette	17.20	.....	.....	.....	.....	.....	17.20
Macon	17.91	.....	14.04	15.44	15.76	23.20	21.07
Carey	12.31	.....	14.10	.....	.....	.....	.....
Average run-off	18.61	.....	14.07	15.44	16.39	23.19	21.23
Percentage of rainfall	36.48	.....	31.06	28.43	38.01	39.66	36.31

EASTERN GULF DRAINAGE.

The rivers flowing into the eastern portion of the Gulf of Mexico are for the most part of a character similar to those in the Southern Atlantic drainage, though in their lower courses their flow is usually more sluggish. Regular gaging stations have been maintained during the year 1901 as follows: On Flint River at Woodbury, Ga., and Albany, Ga.; on Chattahoochee River near Gainesville, Ga., near Buford, Ga., at Oakdale, Ga., and at West Point, Ga.; on Etowah River at Canton, Ga.; Coosawattee River at Carters, Ga.; on Oostanaula River at Resaca, Ga.; on Coosa River at Rome, Ga., near Riverside, Ala., and at Locks Nos. 4 and 5, Alabama; on Talladega Creek at Nottingham, Ala.; on Hillabee Creek near Alexander City, Ala.; on Big Sandy Creek near Dadeville, Ala.; on Tallapoosa River near Sturdevant, Ala., near Susanna, Ala., and near Milstead, Ala.; on Alabama River at Montgomery, Ala., and at Selma, Ala.; on Cahaba River at Centerville, Ala.; on Mulberry Fork of Black Warrior River near Cordova, Ala.; on Black Warrior River at Tuscaloosa,

Ala.; on Tombigbee River at Columbus, Miss., and at Epes, Ala.; and on Pearl River at Jackson, Miss. The locations of the river stations in the Apalachicola and Mobile river basins are shown in figs. 24 and 36.

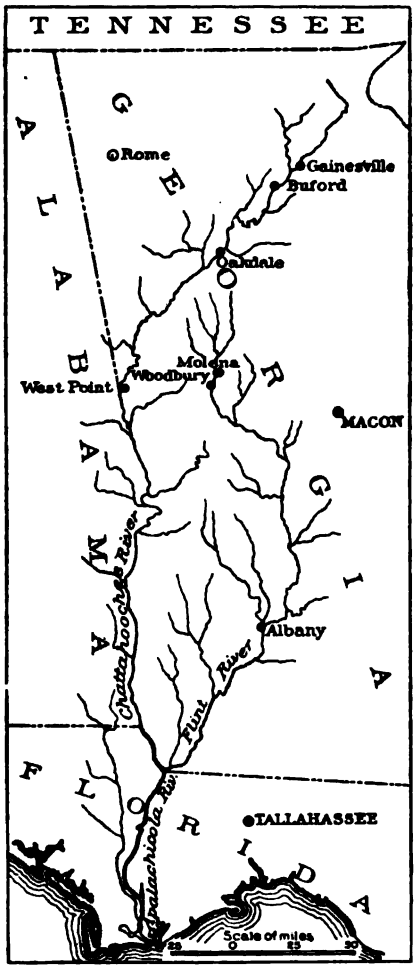


FIG. 24.—Drainage basin of Apalachicola River.

The floods that occurred during the year 1901 on the rivers of the southeastern States have been of marked severity, notably the high water of December 29 to 31, which resulted in the destruction of a number of masonry mill dams and other valuable property.

APALACHICOLA RIVER.

Estimated monthly discharge of Flint River at Woodbury, Ga.

[Drainage area, 988 square miles.]

Month.	Discharge in second-feet.			Run-off	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,840	1,370	2,803	2.84	3.27
February	6,820	1,120	2,395	2.42	2.52
March	7,100	800	1,774	1.80	2.08
April	9,900	890	2,818	2.85	3.18
May	13,260	580	2,285	2.31	2.66
June	3,740	580	1,617	1.64	1.83
July	2,200	460	780	.79	.91
August	10,460	460	2,467	2.50	2.88
September	5,980	460	1,249	1.26	1.41
October	3,040	430	679	.69	.80
November	650	460	526	.53	.59
December	14,100	530	2,005	2.03	2.34
The year	14,100	430	1,783	1.81	24.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 266; rating table on page 321 of same paper.

Estimated monthly discharge of Chattahoochee River near Buford, Ga.

[Drainage area, 1,050 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
June 24 to 30			3,554	3.38	0.88
July	8,768	1,700	2,507	2.39	2.76
August	18,064	1,450	4,985	4.75	5.48
September	10,224	2,300	3,031	2.89	3.22
October	3,105	1,560	1,863	1.77	2.04
November	1,630	1,450	1,537	1.46	1.63
December	23,100	1,450	3,624	3.45	3.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 268; rating table on page 321 of same paper.

Estimated monthly discharge of Chattahoochee River at Oakdale, Ga.

[Drainage area, 1,560 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	24,180	2,044	5,191	3.33	3.84
February	5,028	2,272	3,214	2.06	2.15
March	25,890	2,044	4,929	3.16	3.65
April	12,780	2,846	5,149	3.30	3.68
May	21,900	2,511	4,624	2.96	3.42
June	10,500	2,934	4,749	3.04	3.39
July	9,474	2,040	3,225	2.07	2.39
August	21,672	1,829	7,697	4.93	5.69
September	15,744	2,676	4,145	2.66	2.97
October	4,344	1,758	2,600	1.67	1.93
November	1,898	1,690	1,763	1.13	1.26
December	29,880	1,690	4,285	2.75	3.17
The year	29,880	1,690	4,298	2.75	37.54

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 269; rating table on page 322 of same paper.

Estimated monthly discharge of Chattahoochee River at West Point, Ga.

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	42,630	4,920	11,748	3.56	4.11
February	37,100	4,920	10,015	3.03	3.16
March	33,410	4,280	7,952	2.41	2.78
April	23,360	4,920	11,022	3.34	3.73
May	52,750	4,700	10,814	3.28	3.79
June	16,110	4,920	8,487	2.57	2.87
July	12,456	3,000	4,964	1.50	1.73
August	52,290	3,000	12,982	3.93	4.54
September	32,030	3,520	7,145	2.16	2.41
October	11,628	2,840	3,883	1.18	1.36
November	4,280	2,380	2,835	.86	.96
December	88,630	2,380	12,116	3.67	4.24
The year	88,630	2,380	8,664	2.62	35.68

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 270; rating table on page 322 of same paper.

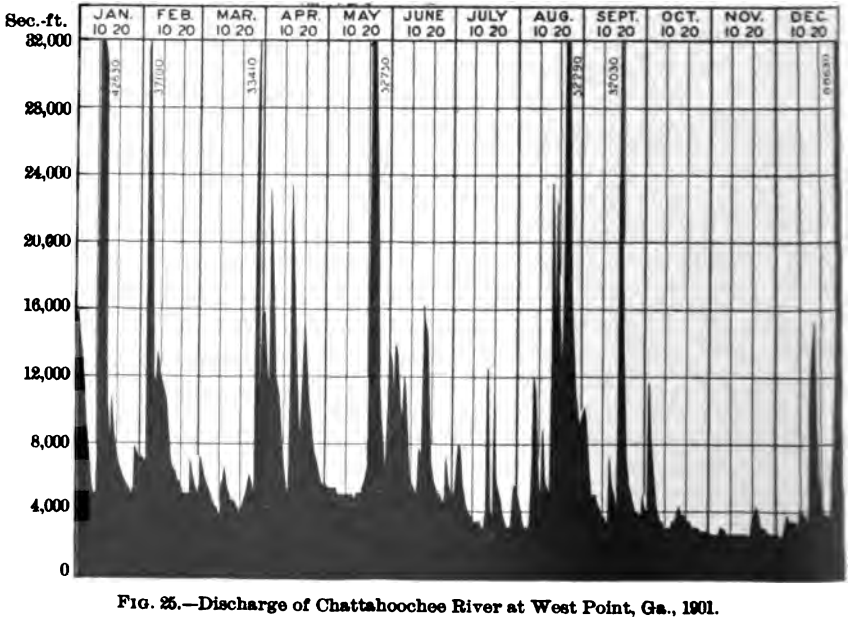


FIG. 25.—Discharge of Chattahoochee River at West Point, Ga., 1901.

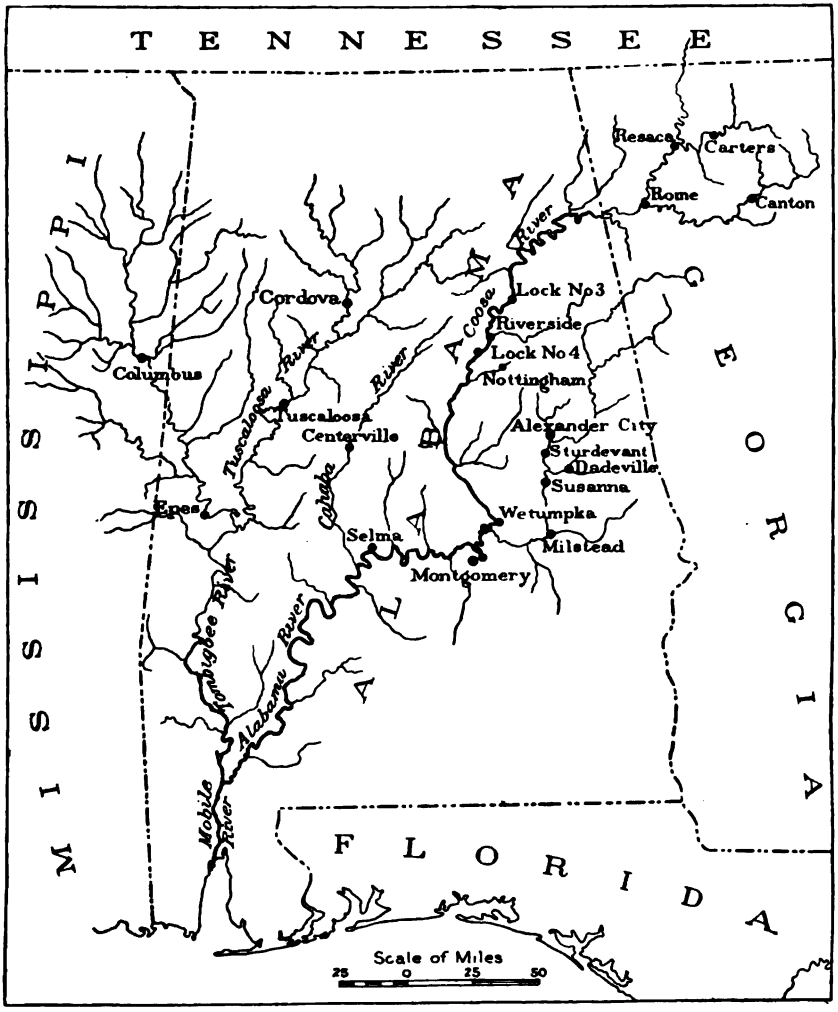


FIG. 26.—Drainage basin of Mobile River.

TALLAPOOSA RIVER.

Estimated monthly discharge of Hillabee Creek near Alexander City, Ala.

[Drainage area, 214 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	3,074	146	370	1.73	1.93
October	2,106	146	387	1.81	2.09
November	2,502	184	471	2.20	2.45
December	2,150	263	716	3.35	3.86
1901.					
January	3,030	566	1,198	5.60	6.46
February	3,646	566	920	4.30	4.48
March	1,798	434	617	2.88	3.32
April	3,910	566	911	4.26	4.75
May	1,226	434	624	2.92	3.37
June	830	230	439	2.05	2.29
July	1,006	169	357	1.67	1.93
August	1,446	138	535	2.50	2.89
September	654	138	249	1.16	1.29
October	786	138	181	.85	.98
November	169	138	148	.69	.77
December	4,350	138	526	2.46	2.84
The year	4,350	138	559	2.61	35.37

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 271, rating table on page 322 of same paper.

Estimated monthly discharge of Big Sandy Creek near Dadeville, Ala.

[Drainage area, 195 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	880	308	425	2.18	2.51
February	2,700	282	545	2.78	2.90
March	6,392	256	552	2.83	3.26
April	3,428	334	689	3.53	3.94
May	3,220	230	480	2.46	2.84
June	2,492	178	523	2.68	2.99
July	516	152	227	1.16	1.34
August	2,180	115	369	1.89	2.18
September	620	67	257	1.32	1.47
October	1,764	45	462	2.37	2.73
November	115	67	92	.47	.52
December	10,500	85	1,265	6.49	7.48
The year	10,500	45	490	2.51	34.16

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 273; rating table on page 322 of same paper.

Estimated monthly discharge of Tallapoosa River near Susanna, Ala.

[Drainage area, 2,610 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	53,780	5,630	13,265	5.08	5.86
February	44,780	5,630	11,303	4.33	4.51
March	26,330	3,850	7,546	2.89	3.31

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 274; rating table on page 322 of same paper.

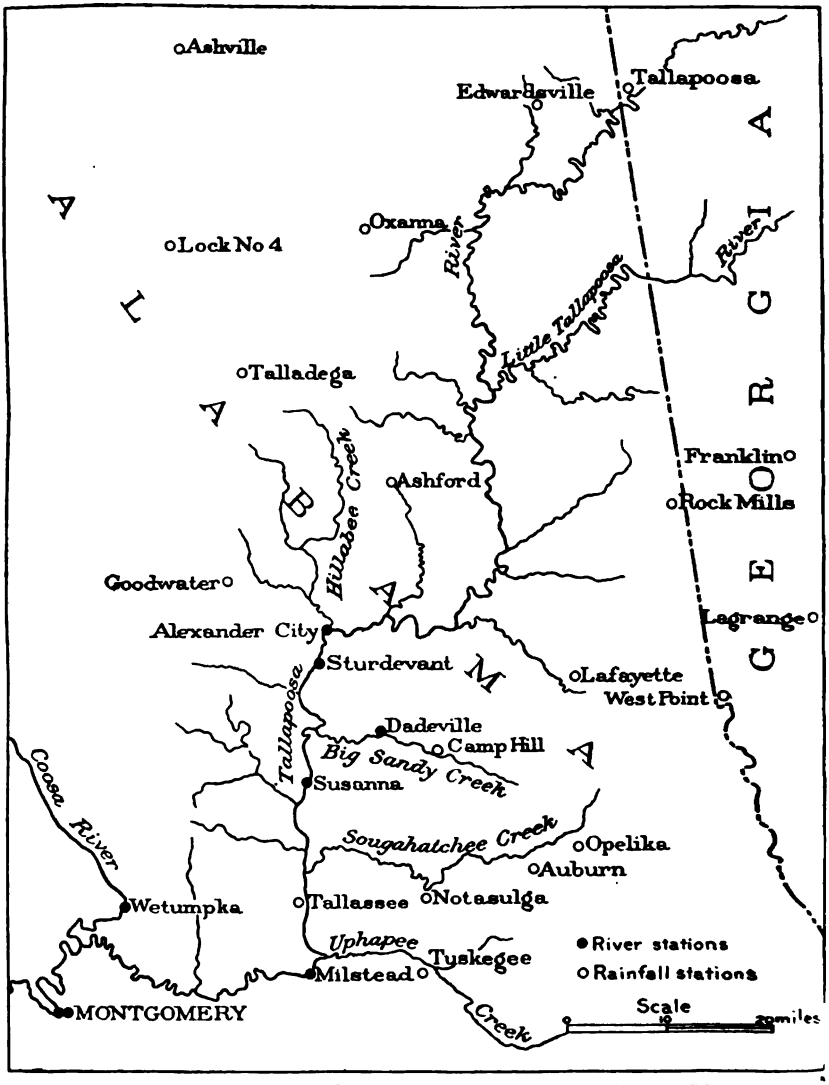


FIG 27.—Location of river and rainfall stations in basin of Tallapoosa River.

Estimated monthly discharge of Tallapoosa River near Milstead, Ala.

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	33,962	5,275	11,476	2.99	3.45
February	28,900	5,837	10,440	2.72	2.83
March	35,087	4,150	8,374	2.18	2.52
April	28,900	5,499	12,020	3.13	3.49
May	17,875	3,587	6,440	1.68	1.94
June	13,262	2,775	5,976	1.56	1.74
July	5,387	2,012	3,398	.88	1.01
August	23,275	2,012	5,904	1.54	1.78
September	9,887	1,675	3,137	.82	.91
October	6,849	1,562	2,364	.62	.71
November	2,237	1,562	1,855	.48	.54
December	[a] 70,000	1,843	8,282	2.16	2.49
The year	[a] 70,000	1,562	6,639	1.73	23.41

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 274; rating table on page 322 of same paper.

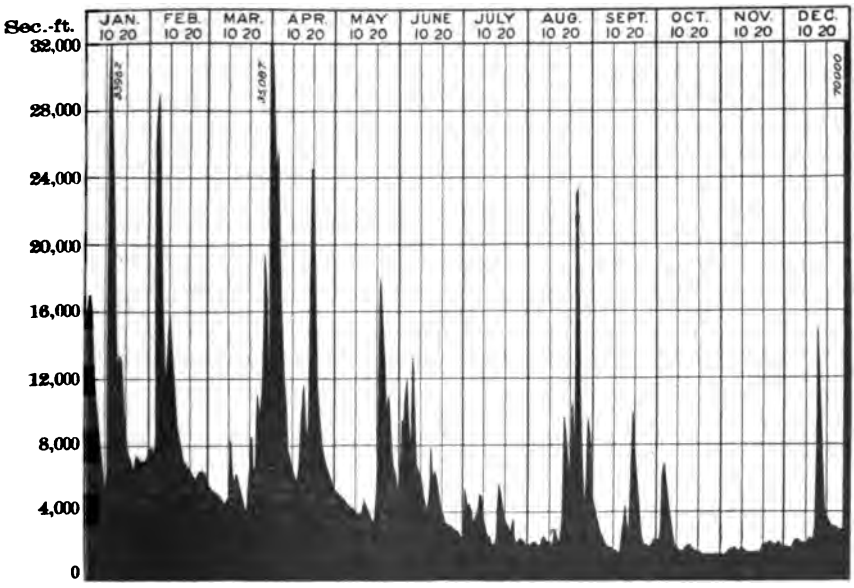


FIG. 28.—Discharge of Tallapoosa River near Milstead, Ala., 1901.

PRECIPITATION IN THE BASIN OF TALLAPOOSA RIVER.

The principal observations of rainfall made within the Tallapoosa River Basin are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 27, in connection with the points of river measurement which are located at Alexander City, Dadeville, Sturdevant, Susanna, and Milstead.

Location of rainfall stations in Tallapoosa River Basin.

Station.	County.	State.	Latitude.	Longitude.	Length of record.
			° ′	° ′	Years.
Ashville	St. Clair	Alabama			6- 7
Goodwater	Coosa	do			6- 9
Lock No. 4	Talladega	do			7- 9
Opelika	Lee	do	32 38	85 25	6-22
Oxanna	Calhoun	do	32 23	86 18	9-11
Tallassee	Elmore	do			8-11
Wetumka	do	do			9-11

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made:

Precipitation at stations in drainage basin of Tallapoosa River.

ASHVILLE, ALA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Normal	4.54	4.65	7.16	6.30	7.90	4.01	5.12	4.48	2.52	2.94	3.04	4.95	57.61
1896	4.42	3.78	4.48	4.21	2.35	3.14	2.22	1.20	1.89	1.09	4.78	1.11	34.67
1897	4.15	6.09	7.42	5.00	1.62	.96	5.17	2.63	.30	1.00	.77	7.04	42.15
1898	5.48	.80	3.40	5.37	.48	2.97	6.81	3.50	3.79	7.53	4.25	2.12	46.14
1899	4.82	6.27	11.14	4.21	1.28	2.46	8.27	3.43	.14	1.30	3.81	6.10	53.23
1900	2.65	7.40	6.35	12.56	2.93	11.98	6.45	1.44	5.35	6.73	3.83	3.41	71.0[illegible]
1901	5.73	3.56	10.14	6.42	5.65	2.65	2.51	11.45	3.81	.56	1.63	10.87	64.9[illegible]

GOODWATER, ALA.

Normal	4.50	5.00	5.68	4.17	2.28	4.37	5.63	4.64	2.18	3.17	3.32	4.62	49.5[illegible]
1896	5.93	4.36	6.39	2.83	3.89	3.36	4.57	.69	3.05	1.05	3.14	.50	3[illegible].76
1897	3.20	4.33	8.38	3.90	.10	3.18	4.16	3.62	.94	.00	(3.32)	(4.62)	3[illegible].7[illegible]
1898	1.45	.75	2.29	4.41	.16	4.92	8.18	9.02	1.37	3.76	5.32	2.20	4[illegible].8[illegible]
1899	5.21	(5.00)	7.26	3.41	2.79	2.27	10.22	3.25	.26	2.21	2.70	5.85	5[illegible].4[illegible]
1900	4.08	10.28	5.85	6.10	2.30	10.35	6.60	4.79	3.44	8.74	5.57	7.38	7[illegible].4[illegible]
1901	7.11	5.26	5.01	4.39	5.31	4.78	6.14	8.54	2.67	1.28	1.84	7.76	6[illegible].0[illegible]

Precipitation at stations in drainage basin of Tallapoosa River—Continued.

LOCK NO. 4, ALABAMA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	5.88	5.23	5.60	4.86	2.85	4.33	6.11	4.62	2.20	2.59	2.82	4.25	51.34
1896	4.50	4.80	4.25	2.44	3.25	4.77	5.85	1.90	1.04	1.71	2.61	.87	37.99
1897	4.69	5.61	8.23	3.64	1.72	.43	4.51	3.45	.73	.74	1.96	6.74	42.45
1898	4.67	.69	4.11	4.18	1.49	5.27	5.60	4.35	2.44	6.82	4.84	2.01	46.47
1899	3.79	7.21	5.86	4.32	2.61	1.38	6.25	3.82	.06	1.19	3.61	7.01	47.11
1900	2.86	7.34	7.30	9.36	3.43	13.06	6.97	2.51	4.43	4.83	5.04	4.26	71.39
1901	11.72	3.96	6.22	6.27	3.98	1.85	3.79	8.64	5.08	2.50	1.10	8.38	63.49

OPELIKA, ALA.

Normal	5.64	5.13	5.28	3.78	3.14	4.33	5.32	4.44	2.64	2.98	3.11	5.09	50.88
1896	6.53	3.87	2.48	1.29	1.63	1.94	5.54	1.39	1.94	1.02	5.10	1.30	34.03
1897	1.25	5.92	9.09	5.37	1.03	.70	6.33	5.38	.96	2.14	3.29	3.33	44.79
1898	4.89	1.85	3.15	4.11	.11	1.26	6.39	9.30	3.43	9.27	7.26	7.66	58.68
1899	7.41	6.42	5.58	2.54	2.39	2.47	3.98	3.69	.31	2.78	1.75	5.96	45.28
1900	3.52	10.87	6.10	4.51	.07	9.89	4.64	4.05	6.16	8.29	7.80	7.17	73.07
1901	9.59	7.14	9.63	7.60	4.09	4.08	3.45	5.82	3.35	.50	1.25	10.88	67.38

OXANNA, ALA.

Normal	5.18	4.90	5.38	4.77	4.07	4.47	5.40	4.30	2.45	1.66	2.75	4.27	49.59
1896	4.13	3.76	3.76	2.64	2.72	4.10	4.25	.98	2.49	1.53	3.80	.66	34,56
1897	3.67	5.29	8.65	2.77	1.73	1.38	7.16	2.91	.00	.53	1.87	6.10	42.06
1898	3.00	.80	3.79	4.17	1.12	2.88	5.19	8.15	1.85	(1.66)	4.32	1.75	38.68
1899	4.36	6.42	5.98	2.99	1.30	2.05	8.81	3.66	.05	1.92	2.50	5.91	45.91
1900	3.95	8.80	5.52	8.99	2.29	10.86	6.41	1.56	4.69	3.52	5.24	3.99	65.82
1901	4.64	4.54	5.17	6.28	6.11	4.73	5.13	7.37	3.16	.70	1.44	8.40	57.67

TALLASSEE, ALA.

Normal	5.11	6.39	6.60	3.65	2.59	4.18	5.01	5.67	2.48	1.97	3.51	5.29	52.45
1896	(5.11)	6.40	5.55	2.72	4.39	(4.18)	(5.01)	(5.67)	(2.48)	(1.97)	(3.51)	1.30	48.29
1897	3.28	7.28	11.25	5.03	1.39	(4.18)	4.53	6.21	(2.48)	.41	1.92	4.11	52.12
1898	2.12	1.91	3.70	5.25	.25	3.71	7.23	7.40	1.35	(1.97)	7.12	(5.29)	47.30
1899	6.62	7.12	4.42	1.83	1.30	2.15	6.82	3.39	.24	3.79	2.17	4.79	44.64
1900	.78	8.84	6.07	5.55	1.58	6.48	(5.01)	4.06	3.20	2.57	4.30	5.55	53.99
1901	6.44	4.08	7.17	4.88	4.89	2.14	2.40	4.65	3.85	.82	1.87	12.77	55.91

WETUMKA, ALA.

Normal	4.80	5.13	5.39	4.41	3.23	3.37	5.19	4.75	2.07	2.94	3.14	4.78	49.20
1896	6.49	5.46	5.54	3.33	4.26	6.74	5.69	4.51	1.62	1.13	3.02	1.78	49.57
1897	2.92	5.81	14.02	5.46	.93	.86	2.04	6,73	1.78	.20	2.47	4.36	47.58
1898	2.12	2.15	3.03	6.05	.62	2.00	7.74	8.52	1.93	3.84	6.71	3.87	48.58
1899	6.95	6.15	3.92	2.08	2.76	2.75	6.39	2.41	.22	4.36	2.46	4.62	45.07
1900	3.12	9.30	5.97	6.54	1.88	6.96	2.71	5.52	5.26	7.73	5.13	6.42	66.54
1901	5.07	3.40	6.35	4.93	4.11	2.63	1.96	3.68	3.72	.97	1.44	8.96	47.22

The amount of water delivered from the drainage basin as measured at the points named below has been computed in terms of depth in inches. The normals given are the monthly averages for times during which measurements or computations were had. The figures for the yearly normal are the sums of these monthly averages.

Depth of run-off, in inches, from the drainage basin of Tallapoosa River at Milstead, Ala.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	1.96	2.78	2.50	2.60	1.13	1.28	1.22	1.38	.86	1.09	1.02	1.90	19.70
1898	.72	.52	.69	1.67	.45	.38	.75	2.22	.77	2.19	1.76	1.73	13.85
1899	2.53	4.26	3.72	2.62	1.00	.59	1.50	.67	.29	.30	.53	1.42	19.43
1900	1.12	3.50	3.07	2.62	1.12	2.42	1.63	.84	1.45	1.14	1.23	1.95	22.09
1901	3.45	2.83	2.52	3.49	1.94	1.74	1.01	1.78	.91	.71	.54	2.49	23.41

Rainfall and run-off in basin of Tallapoosa River.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Ashville	57.61	34.67	42.15	46.14	53.23	71.08	64.98
Goodwater	49.56	39.76	39.75	43.83	50.43	75.48	60.09
Lock No. 4	51.34	37.99	42.45	46.47	47.11	71.39	63.49
Opelika	50.88	34.03	44.79	58.68	45.28	73.07	67.38
Oxanna	49.59	34.56	42.06	38.68	45.91	65.82	57.67
Tallassee	52.45	48.29	52.12	47.30	44.64	53.99	55.91
Wetumka	49.20	49.57	47.58	48.58	45.07	66.54	47.22
Average	51.52	39.74	44.41	47.10	47.38	68.20	59.53
RUN-OFF.							
Tallapoosa at Milstead	19.70	.....	.....	13.85	19.43	22.09	23.41
Percentage of rainfall	38.24	.....	.....	29.41	41.01	32.39	39.32

COOSA RIVER.

Estimated monthly discharge of Etowah River at Canton, Ga.

[Drainage area, 604 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	14,185	988	1,965	3.25	3.75
February	5,470	1,154	2,135	3.53	3.68
March	14,600	988	1,890	3.13	3.61
April	4,474	1,154	2,290	3.81	4.25
May	14,268	1,154	2,394	3.96	4.57
June	4,889	1,154	2,442	4.04	4.51
July	2,648	905	1,317	2.18	2.51
August	11,280	820	2,533	4.19	4.83
September	2,814	988	1,483	2.46	2.74
October	2,897	590	1,039	1.72	1.98
November	1,320	905	1,052	1.74	1.94
December	17,090	988	2,715	4.50	5.19
The year	17,090	590	1,938	3.21	43.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 275; rating table on page 322 of same paper.

Estimated monthly discharge of Coosawattee River at Carters, Ga.

[Drainage area, 531 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	14,790	765	1,625	3.06	3.53
February	5,070	970	1,871	3.52	3.67
March	14,070	815	2,214	4.17	4.81
April	9,750	1,290	2,306	4.34	4.84
May	16,950	917	2,153	4.06	4.68
June	2,694	970	1,538	2.90	3.24
July	1,455	535	923	1.74	2.01
August	16,230	622	2,778	5.23	6.03
September	12,630	970	1,761	3.32	3.70
October	1,075	622	783	1.47	1.69
November	815	622	686	1.29	1.44
December	15,510	765	2,689	5.06	5.83
The year	16,950	535	1,777	3.35	45.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 277; rating table on page 322 of same paper.

Estimated monthly discharge of Oostanaula River at Resaca, Ga.[a]

[Drainage area, 1,614 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	22,274	1,700	6,222	3.86	4.45
February	12,522	1,880	4,655	2.88	3.00
March	21,446	1,700	5,597	3.47	4.00
April	16,846	2,870	6,699	4.15	4.63
November 13–30			1,211	.75	.50
December	22,182	1,000	5,958	3.69	4.25

[a] Half year station.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 278; rating table on page 322 of same paper.

Estimated monthly discharge at Coosa River at Rome, Ga.

[Drainage area, 4,006 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	52,930	4,600	15,450	3.86	4.45
February	35,845	4,900	12,186	3.04	3.17
March	52,930	4,600	13,406	3.34	3.85
April	36,046	6,901	15,578	3.88	4.33
May	51,724	4,150	12,533	3.12	3.60
June	19,966	4,450	8,316	2.08	2.32
July	9,715	2,850	4,441	1.10	1.27
August	45,292	2,850	13,780	3.44	3.97
September	21,172	3,120	6,389	1.59	1.77
October	5,230	2,350	3,414	.85	.98
November	2,850	2,110	2,316	.58	.65
December	64,186	2,475	13,428	3.35	3.86
The year	64,186	2,110	10,103	2.52	34.22

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 278; rating table on page 322 of same paper.

Estimated monthly discharge of Coosa River near Riverside, Ala.

[Drainage area, 7,065 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	55,900	8,970	26,089	3.69	4.25
February	41,100	8,970	21,784	3.08	3.21
March	56,700	7,400	20,613	2.92	3.37
April	51,100	14,500	30,616	4.33	4.83
May	40,700	6,670	16,195	2.29	2.64
June	26,100	6,810	12,335	1.75	1.95
July	10,300	4,900	6,535	.93	1.07
August	44,700	4,400	20,370	2.88	3.32
September	23,100	5,700	9,977	1.41	1.57
October	10,300	4,280	5,694	.81	.93
November	4,650	3,830	4,016	.57	.64
December	57,100	4,050	18,885	2.67	3.08
The year	57,100	3,830	16,092	2.28	30.86

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 279; rating table on page 322 of same paper.

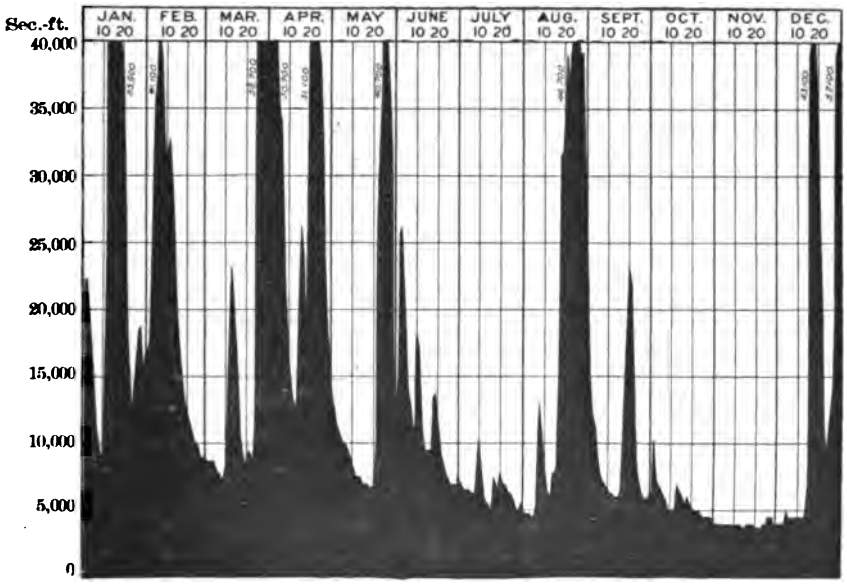


FIG. 29.—Discharge of Coosa River near Riverside, Ala., 1901.

Estimated monthly discharge of Talladega Creek at Nottingham, Ala.

[Drainage area, 156 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
August 16–31			113	0.72	0.43
September	2,286	74	575	3.69	4.12
October	636	90	190	1.22	1.41
November	724	130	249	1.60	1.79
December	746	152	291	1.87	2.16
1901.					
January	1,802	284	485	3.11	3.59
February	1,626	306	449	2.88	3.00
March	1,824	240	405	2.60	3.00
April	2,330	328	591	3.79	4.23
May	724	240	306	1.96	2.26
June	526	152	218	1.40	1.56
July	196	130	149	.96	1.11
August	372	90	148	.95	1.10
September	614	90	148	.95	1.06
October	482	90	123	.79	.91
November	152	90	97	.62	.69
December	1,714	90	264	1.69	1.95
The year	2,330	90	282	1.81	24.46

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 281; rating table on page 322 of same paper.

ALABAMA RIVER

Estimated monthly discharge of Alabama River at Selma, Ala.

[Drainage area, 13,500 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	50,110	9,676	26,495	1.96	2.26
February	128,540	10,920	63,763	4.72	4.91
March	89,478	37,874	58,272	4.32	4.98
April	109,960	21,648	60,909	4.51	5.03
May	41,864	13,668	21,090	1.56	1.80
June	94,000	12,220	35,288	2.61	2.91
July	93,468	12,660	33,964	2.52	2.90
August	38,140	9,124	14,156	1.05	1.21
September	52,504	7,189	17,366	1.29	1.44
October	35,480	7,097	14,492	1.07	1.23
November	46,120	7,596	18,506	1.37	1.53
December	48,780	8,750	28,989	2.15	2.48
The year	128,540	7,097	33,772	2.34	32.68
1901.					
January	107,300	22,446	61,213	4.53	5.22
February	95,862	30,692	55,037	4.08	4.25
March	92,670	21,382	39,017	2.89	3.33
April	104,640	32,288	73,048	5.41	6.04
May	59,420	10,120	26,966	2.00	2.31
June	53,568	7,818	26,030	1.93	2.15
July	21,318	7,596	13,536	1.00	1.15
August	66,868	9,532	30,853	2.29	2.64
September	46,120	10,428	19,394	1.44	1.61
October	21,914	7,931	11,022	.82	.95
November	8,750	7,931	8,266	.61	.68
December	94,000	8,511	26,638	1.97	2.27
The year	107,300	7,596	32,585	2.47	32.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 262; rating table on page 326 of same paper.

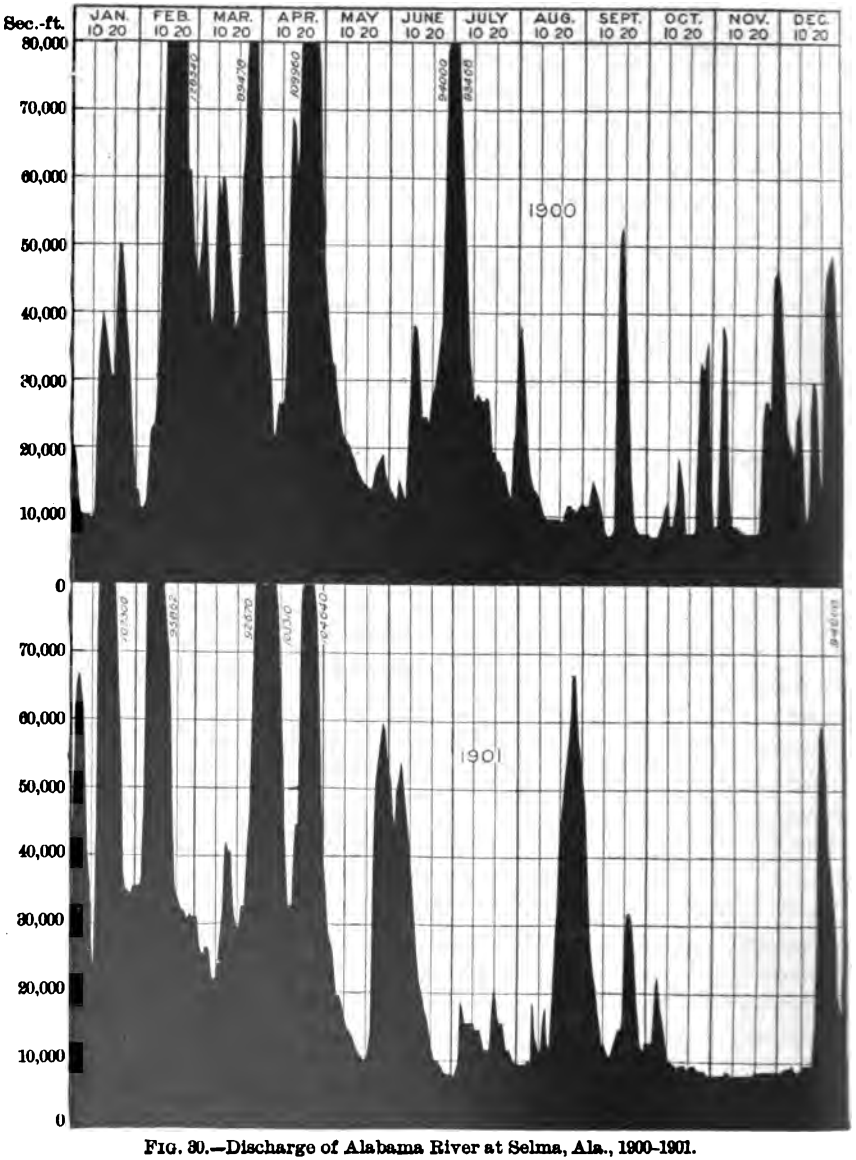


FIG. 30.—Discharge of Alabama River at Selma, Ala., 1900-1901.

BLACK WARRIOR RIVER.

Estimated monthly discharge of Mulberry Fork of Black Warrior River near Cordova, Ala.

[Drainage area, 1,900 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
June	49,284	1,134	16,185	8.52	9.51
July	11,248	810	2,975	1.57	1.81
August	2,144	660	1,016	.53	.61
September	1,951	205	556	.29	.32
October	13,098	60[a]	1,782	.91	1.05
November	6,808	384	1,487	.78	.87
December	6,660	968	2,154	1.13	1.30
1901.					
January	51,800	1,762	8,713	4.59	5.29
February	31,820	1,486	6,616	3.48	3.62
March	29,600	1,486	6,637	3.49	4.02
April	23,088	2,242	6,967	3.67	4.10
May	10,064	968	2,539	1.34	1.54
June	5,920	320	1,582	.83	.93
July	3,404	205	631	.33	.38
August	17,168	205	4,155	2.19	2.53
September	6,660	320	1,415	.74	.83
October	1,669	320	687	.36	.42
November	660	320	468	.25	.28
December	31,820	518	4,923	2.59	2.99
The year	51,800	205	3,778	1.99	26.93

[a] This minimum is estimated from rating curve. The lowest actual discharge measured was at gage height .40, and was 385 second-feet.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 283; rating table on page 323 of same paper.

Estimated monthly discharge of Black Warrior River at Tuscaloosa, Ala.

[Drainage area, 4,900 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	108,375	4,370	22,938	4.68	5.39
February	55,100	4,165	15,094	3.08	3.21
March	40,900	3,815	11,947	2.44	2.81
April	57,020	5,330	17,370	3.55	3.96
May	10,765	2,330	4,355	.89	1.03
June	9,010	850	3,217	.66	.74
July	3,815	415	1,210	.25	.29
August	29,550	340	7,117	1.45	1.67
September	8,660	710	2,626	.54	.60
October	4,775	445	1,536	.31	.36
November	1,022	512	712	.15	.17
December	80,250	710	13,293	2.71	3.12
The year	108,375	340	8,454	1.73	23.35

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 284; rating table on page 323 of same paper.

TOMBIGBEE RIVER.

Estimated monthly discharge of Tombigbee River at Columbus, Miss.

[Drainage area, 4,440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	13,864	2,962	5,588	1.26	1.45
February	16,486	2,686	8,659	1.95	2.03
March	23,938	6,688	15,285	3.42	3.85
April	40,498	3,100	21,265	4.79	5.34
May	13,450	1,464	4,944	1.11	1.28
June	37,600	3,790	27,692	6.24	6.96
July	29,596	2,410	11,411	2.57	2.97
August	10,414	707	2,257	.51	.59
September	1,775	632	950	.21	.23
October	10,138	566	3,989	.90	1.04
November	10,000	1,097	4,304	.97	1.08
December	11,794	1,464	5,239	1.18	1.36
The year	40,498	566	9,299	2.09	28.18
1901.					
January	33,736	2,410	14,193	3.20	3.69
February	24,352	3,790	12,533	2.83	2.95
March	29,182	3,514	10,884	2.45	2.83
April	21,040	3,376	9,890	2.23	2.49
May	11,656	1,328	4,949	1.11	1.28
June	7,792	707	2,767	.62	.69
July	1,097	582	730	.16	.18
August	24,352	582	7,673	1.73	1.99
September	7,240	753	2,008	.45	.50
October	915	650	748	.17	.20
November	1,000	650	756	.17	.19
December	17,590	810	6,730	1.52	1.75
The year	33,736	582	6,155	1.39	18.74

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 285; rating table on page 328 of same paper.

Estimated monthly discharge of Tombigbee River at Epes, Ala.

[Drainage area, 8,830 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	47,100	3,878	25,579	2.90	3.34
February	35,700	6,350	20,999	2.38	2.48
March	30,300	6,350	16,198	1.83	2.11
April	34,500	6,350	18,102	2.05	2.29
May	12,900	3,002	6,880	.78	.90
June	12,900	1,484	4,585	.52	.58
July	1,484	810	1,295	.15	.17
August 16–31			21,541	2.44	1.41
September	7,500	1,484	3,205	.36	.40
October	5,820	1,164	1,633	.18	.21
November	2,200	880	1,550	.18	.20
December	30,900	1,960	12,249	1.39	1.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 286; rating table on page 323 of same paper.

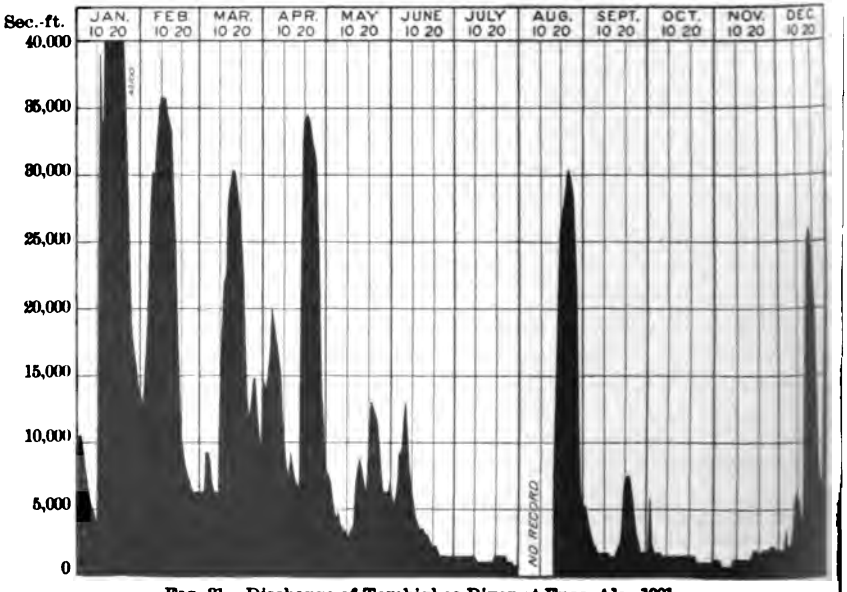


FIG. 31.—Discharge of Tombigbee River at Epes, Ala., 1901.

EASTERN MISSISSIPPI RIVER DRAINAGE.

For convenience of classification the tributaries of the Mississippi River draining from the east and including the main river above its junction with the Missouri, have here been grouped together. These eastern tributaries vary widely in character, both as regards type of rivers and the topography of the areas which they drain. Those draining the comparatively low rolling country adjacent to the valley of the Mississippi are as a rule sluggish streams with few falls of importance, while the upper Ohio River and its numerous tributaries, on the contrary, drain a country of high elevations, their upper courses being through narrow V-shaped valleys, with frequent falls and with high rocky banks. Owing to the steep slopes the run-off is rapid, causing sudden fluctuations in the streams and giving rise to the high floods and extreme low waters for which the Ohio Basin is noted, and the influence of which is felt to a marked degree even in the flow of Mississippi River below Cairo.

Systematic records have been kept during 1901 at numerous points along the principal tributaries of the Ohio River, on the Mississippi River at St. Paul, and on the Yazoo River at Yazoo City.

UPPER OHIO RIVER.

Estimated monthly discharge of Youghiogheny River at Friendsville, Md.

[Drainage area, 295 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,942	575	803	2.72	3.14
February	600	600	600	2.03	2.11
March	4,450	600	1,824	6.18	7.12
April	4,336	865	2,103	7.13	7.96
May	3,082	400	1,167	3.96	4.57
June	1,942	300	692	2.35	2.62
July	785	130	231	.78	.90
August	400	130	194	.66	.76
September	300	95	159	.54	.60
October	130	95	105	.36	.42
November	350	95	176	.60	.67
December	5,362	300	1,651	.56	.65
The year	5,362	95	809	2.32	31.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 289; rating table on page 323 of same paper.

Estimated monthly discharge of Cheat River near Uneva, W. Va.

[Drainage area 1,375 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	.....	.....	1,370	1.00	1.00
August	2,232	357	924	.67	.77
September	3,210	404	952	.69	.77
October	465	273	336	.24	.28
November	3,070	538	1,732	1.26	1.41
December	6,442	1,000	2,387	1.74	2.01
1900.					
July	4,610	730	1,888	1.37	1.58
August	1,956	273	614	.45	.52
September	730	190	254	.18	.20
October	730	190	340	.25	.29
November	3,070	273	903	.66	.59
December	7,270	1,136	2,682	1.95	2.03

NOTE.—Gage heights and discharge measurements have been published as follows: For 1899, in Water-Supply Paper No. 36, page 160; for 1900, in Water-Supply Paper No. 48, page 177; rating table in Water-Supply Paper No. 65, page 323; later measurements on page 290 of same paper.

GREAT KANAWHA RIVER.

Estimated monthly discharge of Greenbrier River at Alderson, W. Va.

[Drainage area, 1,344 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,050	590	2,339	1.74	2.01
February	2,440	590	1,031	.77	.80
March	14,300	590	2,685	2.00	2.31
April	19,340	1,535	6,320	4.70	5.24
May	20,875	857	4,349	3.24	3.74
June	20,530	920	3,938	2.93	3.27
July	4,080	280	1,277	.95	1.10
August	2,550	250	845	.63	.73
September	2,110	280	689	.51	.57
October	315	145	230	.17	.20
November	425	120	188	.14	.16
December	37,700	250	4,765	3.55	4.10
The year	37,700	120	2,388	1.78	24.23

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 290; rating table on page 328 of same paper.

Estimated monthly discharge of New River at Radford, Va.

[Drainage area, 2,725 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1898.					
August	16,080	2,220	4,257	1.56	1.80
September	31,160	1,800	5,587	2.05	2.29
October	49,880	2,450	9,068	3.33	3.84
November	4,765	2,450	3,475	1.28	1.43
December	11,920	2,970	4,806	1.76	2.03
1899.					
January	19,200	3,250	5,595	2.05	2.36
February	28,040	2,970	12,521	4.60	4.79
March	53,000	7,240	18,126	6.65	7.68
April	19,720	3,860	8,493	3.12	3.48
May	9,320	2,970	5,390	1.98	2.28
June	18,680	2,000	4,307	1.58	1.76
July	3,860	1,400	2,043	.75	.86
August	4,290	1,400	1,968	.72	.83
September	6,720	1,400	2,513	.92	1.03
October	2,000	1,400	1,452	.53	.61
November	3,860	950	1,645	.60	.67
December	20,240	950	3,165	1.16	1.34
The year	53,000	950	5,602	2.06	27.69
1900.					
January	14,000	1,800	4,173	1.53	1.76
February	23,360	2,000	6,802	2.50	2.60
March	32,720	3,860	11,244	4.13	4.76
April	19,200	2,970	6,656	2.44	2.72
May	8,800	3,250	4,156	1.53	1.76
June	8,800	2,970	4,824	1.77	1.97
July	9,840	1,400	2,635	.97	1.12
August	2,220	575	1,209	.44	.51
September	13,220	600	2,239	.82	.91
October	118,000	850	7,810	2.87	3.31
November	38,960	2,000	5,371	1.97	2.20
December	21,800	2,700	5,315	1.95	2.25
The year	118,000	575	5,203	1.91	25.87

Estimated monthly discharge of New River at Radford, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	22,320	2,220	4,325	1.59	1.83
February	6,200	1,600	3,155	1.16	1.21
March	24,400	675	4,587	1.68	1.94
April	128,400	3,540	16,214	5.95	6.64
May	137,760	3,860	16,651	6.11	7.05
June	42,080	5,715	14,807	5.43	6.06
July	34,800	3,860	8,997	3.30	3.80
August	106,560	3,540	21,850	8.02	9.24
September	32,200	3,540	8,264	3.03	3.38
October	14,000	2,220	4,604	1.69	1.95
November	4,765	1,400	2,092	.77	.86
December	99,800	1,600	15,605	5.73	6.60
The year	137,760	675	10,096	3.71	50.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 298; rating table on page 323 of same paper.

Estimated monthly discharge of New River at Fayette, W. Va.

[Drainage area, 6,200 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	29,100	5,520	11,220	1.81	2.09
February	12,350	5,520	8,036	1.30	1.35
March	32,400	5,520	12,775	2.06	2.38
April [a]	107,740	14,946	41,855	6.75	7.53
May 1–22 [a]	60,430	11,100	17,700	2.85	2.33

[a] Approximate from Apr. 21 to May 4.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 294.

TENNESSEE RIVER.

Estimated monthly discharge of French Broad River near Asheville, N. C.

[Drainage area, 967 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	12,940	2,170	3,206	3.25	3.75
February	4,135	2,055	2,396	2.42	2.51
March	22,220	1,945	4,166	4.22	4.86
April	15,655	3,145	6,772	6.86	7.65
May	24,160	2,620	5,043	5.11	5.89
June	10,800	3,060	4,852	4.92	5.49
July [a]					
August	20,320	2,000	10,740	10.88	12.54
September	11,500	2,760	5,132	5.20	5.80
October	7,300	2,170	2,810	2.84	3.28
November	2,170	1,890	1,984	2.01	2.24
December	26,350	1,890	6,288	6.37	7.35

[a] No record.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 301; rating table on page 323 of same paper.

Estimated monthly discharge of Tennessee River at Knoxville, Tenn.

[Drainage area, 8,990 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	19,322	3,850	8,717	0.97	1.12
February	56,505	4,850	18,202	2.02	2.10
March	58,830	15,818	28,349	3.15	3.64
April	27,210	11,082	14,942	1.66	1.85
May	11,082	6,170	8,179	.91	1.05
June	33,720	5,882	12,860	1.43	1.60
July	25,350	5,322	9,867	1.10	1.27
August	11,082	4,250	5,697	.63	.73
September	14,570	3,450	5,722	.64	.71
October	41,160	3,450	7,568	.84	.97
November	42,090	4,850	10,282	1.14	1.27
December	28,140	6,462	10,814	1.20	1.38
The year	58,830	3,450	11,767	1.31	17.69

Estimated monthly discharge of Tennessee River at Knoxville, Tenn.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	60,225	7,062	17,154	1.91	2.20
February	18,822	6,760	12,202	1.36	1.42
March	71,850	6,760	16,188	1.80	2.08
April	76,965	16,242	37,089	4.13	4.61
May	146,250	10,010	30,837	3.43	3.96
June	44,880	13,362	23,340	2.60	2.90
July	20,237	6,760	11,622	1.29	1.49
August	77,430	6,760	34,046	3.79	4.37
September	36,510	8,322	15,342	1.71	1.91
October	15,398	6,170	8,546	.95	1.10
November	6,760	5,050	5,698	.63	.70
December	141,600	5,322	30,796	3.43	3.95
The year	146,250	5,050	20,238	2.25	30.69

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 303; rating table on page 324 of same paper.

Estimated monthly discharge of Tuckasegee River at Bryson, N. C.

[Drainage area, 662 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	19,580	1,015	2,432	3.67	4.23
February	3,675	950	1,538	2.32	2.41
March	17,550	950	2,862	4.32	4.98
April	11,125	2,255	3,828	5.78	6.45
May	26,250	1,370	3,536	5.34	6.15
June	3,675	1,700	2,255	3.41	3.81
July	2,850	830	1,250	1.89	2.18
August	19,000	710	4,653	7.03	8.10
September	5,515	1,295	2,003	3.02	3.37
October	2,650	830	1,034	1.56	1.80
November	950	600	707	1.07	1.19
December	35,820	600	4,285	6.47	7.46
The year	35,820	600	2,532	3.82	52.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 304; rating table on page 324 of same paper.

A. GREENBRIER RIVER NEAR WHITE SULPHUR SPRINGS, W. VA.

B. GAGING STATION ON TENNESSEE RIVER AT CHATTANOOGA, TENN.

Estimated monthly discharge of Little Tennessee River at Judson, N. C.

[Drainage area, 675 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	13,800	1,250	2,349	3.48	4.01
February	2,955	1,250	1,642	2.43	2.53
March	23,650	1,185	2,277	4.86	5.60
April	14,000	1,725	3,987	5.91	6.59
May	40,580	1,250	3,762	5.57	6.43
June	7,560	1,435	2,740	4.06	4.53
July	3,510	1,125	1,745	2.59	2.99
August	22,125	1,125	6,183	9.16	10.56
September	3,140	1,250	1,550	2.30	2.57
October	3,125	1,125	1,374	2.04	2.36
November	1,125	785	909	1.35	1.51
December	57,540	735	8,120	12.00	13.83
The year	57,540	735	3,136	4.65	63.51

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 305; rating table on page 324 of same paper.

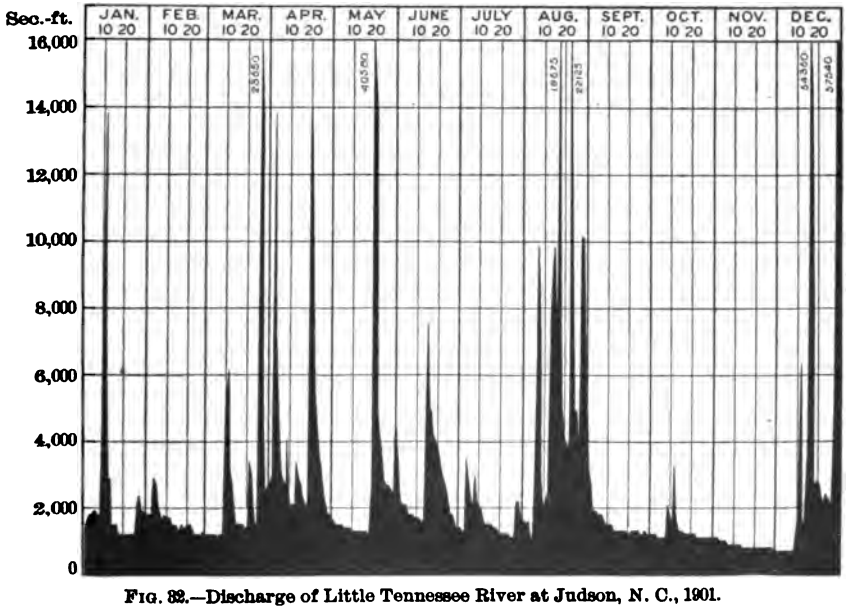


FIG. 32.—Discharge of Little Tennessee River at Judson, N. C., 1901.

Estimated monthly discharge of Hiwassee River at Murphy, N. C.

[Drainage area, 410 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	6,960	670	1,599	3.90	4.50
February	3,990	750	1,429	3.49	3.63
March	9,840	710	1,554	3.79	4.37
April	10,920	1,380	2,535	6.18	6.89
May	9,480	750	1,941	4.73	5.45
June	2,100	840	1,265	3.09	3.45
July	3,180	520	829	2.02	2.33
August	13,260	450	3,068	7.48	8.62
September	3,360	750	1,254	3.06	3.42
October	1,560	485	627	1.53	1.76
November	630	420	484	1.18	1.32
December	14,340	450	1,976	4.82	5.55
The year	14,340	420	1,547	3.77	51.29

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 306; rating table on page 324 of same paper.

Estimated monthly discharge of Nottely River at Ranger, N. C.

[Drainage area, 272 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
February 16–28	----------	----------	514	1.89	0.91
March	3,410	440	774	2.85	3.29
April	2,000	620	956	3.51	3.92
May	3,860	410	894	3.29	3.79
June	1,460	530	790	2.90	3.24
July	2,300	380	639	2.35	2.71
August	4,100	290	1,486	5.46	6.29
September	2,660	530	823	3.03	3.38
October	590	350	463	1.70	1.96
November	560	350	386	1.42	1.58
December	5,360	380	927	3.41	3.93

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 308; rating table on page 324 of same paper.

Estimated monthly discharge of Hiwassee River at Reliance, Tenn.

[Drainage area, 1,180 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	30,800	1,805	5,015	4.25	4.91
February	12,560	1,485	3,448	2.92	3.04
March	34,640	1,805	4,595	3.89	4.49
April	25,040	3,350	6,282	5.32	5.93
May	37,520	2,170	5,468	4.63	5.35
June	7,250	2,375	3,576	3.03	3.38
July	3,620	1,485	2,116	1.79	2.06
August	33,680	1,340	8,190	6.94	8.00
September	5,790	2,375	3,348	2.84	3.17
October	2,375	1,340	1,796	1.52	1.75
November	1,805	1,340	1,494	1.27	1.42
December	32,240	1,340	6,257	5.30	6.12
The year	37,520	1,340	4,299	3.68	49.62

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 308; rating table on page 324 of same paper.

Estimated monthly discharge of Hiwassee River at Charleston, Tenn.

[Drainage area, 2,297 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,000	3,550	7,774	3.38	3.90
February	13,845	3,695	5,860	2.55	2.66
March	29,505	3,550	7,549	3.28	3.79
April	28,780	5,725	10,384	4.51	5.03
May	35,740	3,985	8,999	3.91	4.51
June	12,540	4,275	6,329	2.75	3.07
July	6,595	2,825	3,789	1.65	1.90
August	25,735	2,390	11,052	4.81	5.55
September	16,165	3,840	5,624	2.45	2.73
October	5,290	2,825	3,340	1.45	1.67
November	3,405	2,390	2,709	1.18	1.32
December	37,190	2,390	8,840	3.84	4.43
The year	37,190	2,390	6,854	2.98	40.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 309; rating table on page 324 of same Paper.

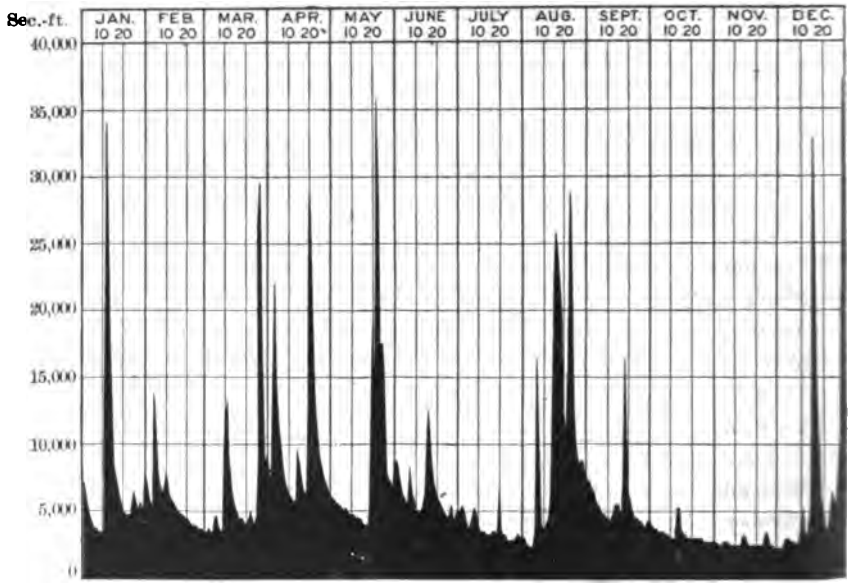


FIG. 33.—Discharge of Hiwassee River at Charleston, Tenn., 1901.

Estimated monthly discharge of Toccoa River, near Blueridge, Ga.

[Drainage area, 231 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,228	552	1,100	4.76	5.49
February	1,590	552	765	3.31	3.44
March	4,800	666	1,077	4.66	5.37
April	3,195	1,062	1,458	6.31	7.04
May	9,080	666	1,599	6.92	7.98
June	1,590	666	1,011	4.38	4.88
July	1,590	666	768	3.32	3.82
August	12,290	666	2,248	9.73	11.22
September	1,590	666	1,144	4.95	5.52
October	804	552	619	2.68	3.09
November	552	460	493	2.13	2.38
December	10,150	552	2,248	9.73	11.22
The year	12,290	460	1,211	5.24	71.45

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 310; rating table on page 324 of same Paper.

Estimated monthly discharge of Tennessee River at Chattanooga, Tenn.

[Drainage area, 21,418 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	189,200	19,600	50,641	2.36	2.72
February	59,850	19,050	36,516	1.70	1.77
March	139,150	19,050	44,952	2.10	2.42
April	166,450	38,400	95,080	4.44	4.95
May	205,450	26,380	68,736	3.21	3.70
June	72,200	33,850	47,673	2.23	2.49
July	37,100	14,680	23,932	1.12	1.29
August	207,400	13,800	75,761	3.54	4.08
September	61,150	22,660	38,859	1.81	2.02
October	25,760	13,360	18,979	.89	1.03
November	13,800	11,660	13,076	.61	.68
December	237,300	12,080	65,509	3.06	3.53
The year	237,300	11,660	48,310	2.26	30.68

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 311; rating table on page 324 of same Paper.

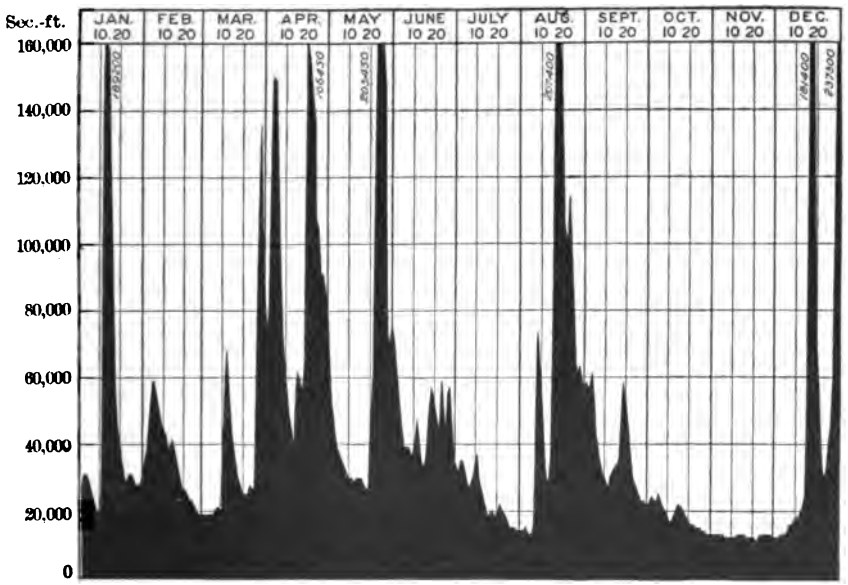


FIG. 34.—Discharge of Tennessee River at Chattanooga, Tenn., 1901.

GREAT LAKES DRAINAGE.

Stations have been maintained, as in past years, on Sandusky River at Fremont, Ohio, and on Maumee River near Waterville, Ohio, but owing to lack of sufficient discharge measurements the flow of the former during 1901 has not been computed. Stations were maintained during 1901 on Grand River at North Lansing, Mich., and at several points in the city of Grand Rapids, Mich. Results of measurements made of Grand River at the Chicago and West Michigan Railroad bridge at Grand Rapids, Mich., are given for the years 1897 to 1900, the records of daily discharge of which were published in Water-Supply Paper No. 49, page 243.

MAUMEE RIVER.

In the following pages are given the results of measurements made during 1901 for Maumee River at Waterville, Ohio, together with a comparison of the run-off from the drainage basin with the precipitation observed at the rainfall stations in the basin.

Estimated monthly discharge of Maumee River near Waterville, Ohio.

[Drainage area, 6,111 square miles.]

Month.	Discharge in second-feet.			Run-off.			Rainfall.
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of rainfall.	
1901.							*Inches.*
January	6,110	480	2,389	0.391	0.451	23.7	1.90
February	9,450	580	3,716	.608	.633	43.6	1.45
March	27,600	2,240	11,207	1.834	2.114	81.9	2.58
April	8,160	1,020	3,646	.596	.658	30.2	2.18
May	22,750	530	3,147	.515	.594	15.3	3.90
June	15,220	660	3,599	.589	.657	17.1	3.84
July	14,215	80	2,503	.410	.473	15.5	3.06
August	140	5	47	.008	.009	.3	2.74
September	80	10	42	.007	.008	.6	1.35
October	1,020	10	246	.040	.046	1.7	2.73
November	180	60	98	.016	.018	1.2	1.53
December	11,200	110	2,585	.423	.488	13.5	3.63
The year	27,600	5	2,771	.453	6.149	19.9	30.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 313

PRECIPITATION IN BASIN OF MAUMEE RIVER.

The principal observations of rainfall made within the basin of Maumee River are at the stations enumerated in the following table, which gives the precipitation by months for 1901. The figures of

average monthly precipitation derived from this table are compared in the next preceding table with the monthly discharge of Maumee River near Waterville, showing the relation between precipitation and run-off in the basin.

Precipitation at stations in drainage basin of Maumee River.

Station.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1901.													
Angola	3.19	1.98	3.26	2.54	2.75	4.10	5.95	4.58	0.87	6.15	1.81	3.47	40.60
Auburn	1.58	1.44	1.15	1.94	2.45	2.87	1.38	3.71	1.30	3.71	1.15	1.57	24.25
Bluffton	1.17	.98	2.76	2.34	4.16	3.29	1.23	4.79	1.12	3.40	1.50	4.01	30.70
Fort Wayne	1.49	1.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Adrian	2.12	1.31	2.37	1.33	2.53	2.23	1.75	2.05	.97	3.46	1.89	2.91	24.92
Coldwater	2.79	1.75	2.71	2.18	1.78	4.96	4.67	4.10	.73	6.56	1.82	3.25	37.30
Hillsdale	2.53	2.63	2.95	1.98	2.64	3.55	2.68	2.20	.98	5.63	2.00	3.12	32.84
Benton Ridge	1.42	2.10	3.15	2.03	3.70	3.59	2.66	2.02	1.82	.24	.....	3.59	.....
Bowling Green	2.57	1.30	2.86	2.23	4.91	3.98	4.42	4.38	1.32	1.15	2.33	4.21	35.66
Celina	1.74	.80	3.14	2.27	4.79	3.98	3.24	1.86	1.95	.94	.95	3.58	29.24
Defiance	1.10	1.07	2.35	1.87	3.93	3.47	6.08	2.16	1.54	2.63	1.41	4.14	31.75
Findlay	1.46	1.45	3.30	2.46	4.65	2.79	1.36	2.96	1.85	.86	.94	3.87	37.95
Hedges	1.12	1.03	3.02	2.19	5.28	3.26	1.89	2.25	1.76	2.27	1.35	4.03	29.45
Kenton	2.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Leipsic	1.33	1.70	2.20	1.81	3.95	3.95	3.20	2.14	.....	1.22	1.01	4.43	.....
Montpelier	3.30	1.70	2.44	2.82	3.52	4.01	5.07	2.45	.92	4.09	1.71	3.10	35.03
Napoleon	1.58	1.25	2.51	2.01	4.03	5.10	2.98	2.53	.64	1.73	1.27	3.02	28.65
New Bremen	1.28	.77	1.26	2.11	4.67	5.14	1.68	2.11	1.44	1.09	1.25	3.75	26.55
Ottawa	1.64	1.26	2.60	2.34	4.32	2.46	3.32	2.61	1.61	.59	1.64	2.25	27.64
Swanton	2.01	1.44	2.05	2.12	3.58	6.68	3.71	2.55	1.32	1.36	1.92	3.88	32.62
Van Wert	1.68	1.46	2.04	2.11	6.63	2.32	1.63	1.50	1.74	2.24	1.28	4.64	29.27
Wauseon	2.10	1.38	3.57	2.99	3.67	5.15	2.36	1.93	1.95	2.88	1.61	5.73	35.32
Total	41.81	30.44	51.69	43.67	77.94	76.88	61.26	54.88	25.68	51.96	29.14	72.55	.....
Mean	1.90	1.45	2.58	2.18	3.90	3.84	3.06	2.74	1.35	2.73	1.53	3.63	30.89

GRAND RIVER.

Estimated monthly discharge of Grand River at the Chicago and West Michigan Railroad bridge, Grand Rapids, Mich.

[Drainage area, 4,900 square miles.]

Month.	Mean discharge in second-feet.	Run-off	
		Second-feet per square mile.	Depth in inches.
1897.			
May	2,892	0.59	0.68
June	1,761	.36	.40
July	1,582	.33	.38
August	1,517	.31	.36
September	1,370	.28	.31
October	1,181	.24	.28

Estimated monthly discharge of Grand River at the Chicago and West Michigan Railroad bridge, Grand Rapids, Mich.—Continued.

Month.	Mean discharge in second-feet.	Run-off	
		Second-feet per square mile.	Depth in inches.
1897.			
November	1,488	0.30	0.33
December	2,382	.49	.56
1898.			
January	3,007	.61	.70
February	7,240	1.48	1.54
April	4,933	1.01	1.13
May	2,365	.48	.55
June	1,735	.35	.39
July	1,487	.30	.35
August	1,867	.38	.44
September	1,694	.35	.39
October	1,833	.37	.43
November	2,645	.54	.60
December	3,024	.62	.71
1899.			
January	6,965	1.42	1.64
February	4,723	.96	1.00
March	9,643	1.97	2.27
April	10,708	2.18	2.43
May	3,088	.63	.72
June	2,236	.46	.52
July	1,719	.35	.40
August	1,617	.33	.38
September	1,741	.36	.40
October	1,715	.35	.40
November	1,798	.37	.41
December	2,059	.42	.48
The year	4,001	.82	11.05
1900.			
January	2,620	.53	.61
February	7,524	1.53	1.59
March	5,945	1.21	1.39
April	11,991	2.45	2.73

HUDSON BAY DRAINAGE.

During the year 1901 systematic measurements were commenced in the basin of Red River of the North within the United States, under the direction of Prof. Charles M. Hall, director of the State agricultural and economic survey of North Dakota. Red River has its source in Lake Traverse and in its course through the United States forms the boundary between the States of Minnesota and North and South Dakota, draining a broad level area of highly fertile lands. After crossing the international boundary it receives from the west Mouse River, a tributary of considerable length, which drains a large area of North Dakota; it then flows into Lake Winnipeg, whence, after mingling with the waters of the Saskatchewan, it discharges through Nelson River into Hudson Bay.

Stations were maintained during 1901 on Red River at Grand Forks, N. Dak., Moorhead, Minn., and Pembina, N. Dak., and on Red Lake River at Crookston, Minn., with a view to studying the feasibility of irrigating lands in Red River Valley. No results of measurements for 1901 are here published, however, the data being insufficient for the present to warrant computation of the flow at these points.

ST. MARY RIVER.

In connection with the contemplated water storage and diversion of St. Mary River into Milk River, a station was established during 1901 on St. Mary River at Main, Mont. The river is a tributary of Belly River, which in its turn flows into the Saskatchewan. A full description of St. Mary River was published in the Twenty-second Annual Report, Part IV, pages 268 to 271, and additional information is set forth in the following pages, relating to the diversion scheme alluded to.

Estimated monthly discharge of St. Mary River at Main, Mont.

[Drainage area, 298 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
July 14–31	.....	.....	1,906	68,049	6.40	4.29
August	1,574	653	932	57,306	3.13	3.61
September	677	485	576	34,274	1.93	2.15
October	465	326	401	24,657	1.35	1.56
November	345	265	292	17,375	.98	1.09
December	278	220	241	14,819	.80	.92

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 15; rating table on page 170 of same paper.

UPPER MISSOURI RIVER DRAINAGE.

The Missouri is formed by the junction in southeastern Montana, at Three Forks, of Jefferson, Madison, and Gallatin rivers. Its principal tributaries are the Milk and Yellowstone, which for convenience are considered separately. Discharge measurements are in progress on all of these streams, as well as on Crow Creek, a tributary of Missouri River, and on the Upper Missouri proper at Townsend, Mont., where the Missouri River Commission maintains a gage. Results for 1901 are given in the following pages.

PRECIPITATION IN UPPER BASIN OF MISSOURI RIVER.

The principal observations of rainfall made within the basin of the headwaters of Missouri River are at the stations enumerated in the

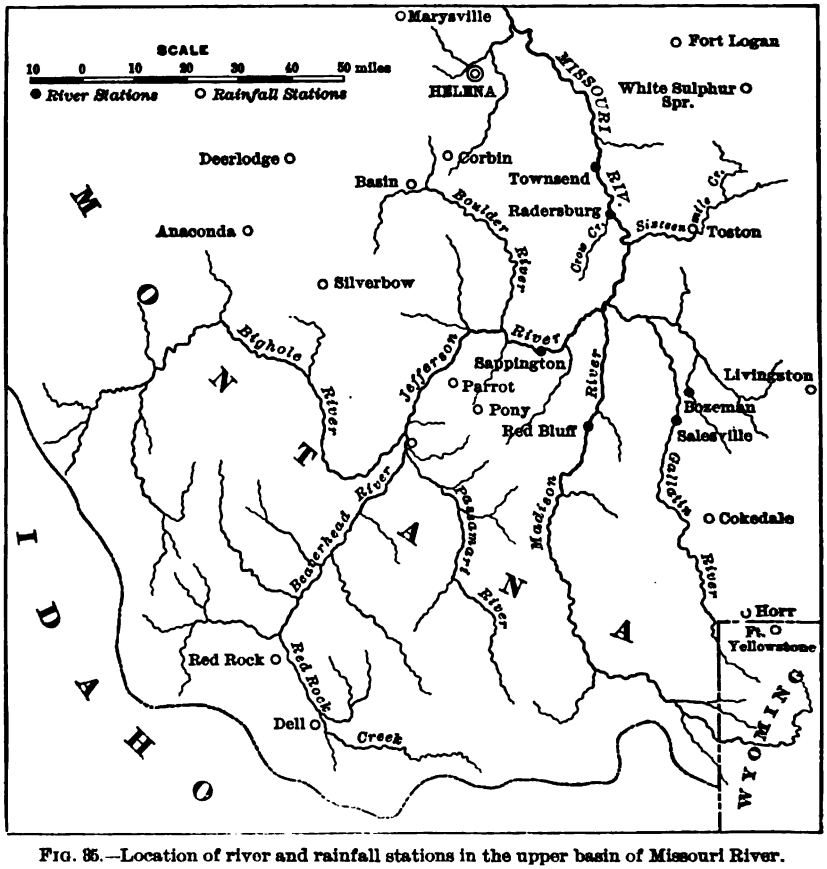


FIG. 35.—Location of river and rainfall stations in the upper basin of Missouri River.

following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 35, in connection with the points of river measurement which are located at Salesville, Logan, Redbluff, Sappington, Bozeman, Radersburg, and Townsend.

Location of rainfall stations in Upper Missouri River Basin.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Butte	Silverbow	Montana				7- 8
Fort Logan	Meagher	do				11-13
Fort Yellowstone.	Yellowstone National Park.	Wyoming	44 58	110 41	6,370	13-16
Helena	Lewis and Clarke	Montana	46 34	112 4		21-22
Livingston	Park	do			4,487	5- 7

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation, the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of Upper Missouri River.

BUTTE, MONT.

Year.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	6.05	0.69	1.04	1.32	1.95	1.62	1.05	0.73	1.16	0.94	0.56	0.77	17.88
1896	.30	.37	.32	.55	1.43	1.07	1.19	.87	1.95	.47	1.62	.37	10.51
1897	1.20	.70	1.04	1.63	1.44	3.02	1.19	.30	.98	1.10	1.52	1.12	15.24
1898	.57	.55	1.56	.51	(1.95)	3.06	.54	.45	.91	(.94)	(.56)	(.77)	12.37
1899	2.35	1.39	1.21	1.57	2.46	.55	.90	2.35	.55	1.65	.14	1.10	16.22
1900	.30	1.05	1.20	2.75	2.90	.66	1.13	.48	1.40	2.08	.20	.40	14.55
1901	.60	.65	1.65	2.35	3.40	2.00	.55	.30	.90	.45	T.	1.70	14.55

FORT LOGAN, MONT.

Normal	0.61	0.48	0.79	1.04	1.89	2.25	0.95	0.60	1.08	0.86	0.89	0.70	12.14
1896	(.61)	.02	.19	.26	1.48	.62	2.90	(.60)	(1.08)	.44	2.71	(.70)	11.61
1897	.62	.62	.74	.82	1.22	3.98	2.21	T.	.48	1.96	2.59	(.70)	15.94
1898	.09	.00	1.68	.66	4.48	3.23	1.76	.49	.40	1.23	2.04	.56	16.62
1899	1.26	.40	.64	.42	.67	(2.25)	T.	1.00	.30	1.71	.10	.82	9.57
1900	T.	.54	.79	1.33	1.61	.67	.15	.49	1.31	1.18	.36	.34	8.77
1901	.72	1.50	.72	1.71	(1.89)	3.59	.70	.85	2.43	.11	T.	1.50	15.72

FORT YELLOWSTONE, WYO.

Normal	2.51	2.15	2.23	1.45	1.91	1.62	1.20	1.15	1.02	1.26	2.20	2.32	21.02
1896	2.21	2.07	2.62	1.29	3.85	.73	2.09	.37	1.10	.06	3.92	.46	20.77
1897	1.12	.83	1.08	1.21	1.55	2.34	1.11	.57	.31	1.72	2.98	.80	15.02
1898	.31	1.21	1.40	.95	1.95	2.67	1.15	2.05	90	2.25	1.55	.67	17 06
1899	4.21	3.40	3.00	2.30	2.52	1.90	1.42	2.23	.90	2.02	.04	1.90	25.84
1900	.92	1.65	3.13	1.93	2.42	1.17	.80	.28	.86	1.22	1.17	1.18	16.73
1901	2.28	.72	1.46	1.08	2.72	1.43	.80	1.65	2.85	.90	1.25	2.53	19.67

Precipitation at stations in drainage basin of Upper Missouri River—Continued.

HELENA, MONT.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	1.15	0.73	0.83	1.17	1.95	2.26	1.07	0.65	1.33	0.85	0.81	0.85	13.65
1896	.72	.59	1.71	1.23	2.25	.71	.89	.86	2.54	.24	3.29	.35	15.3[illegible]
1897	.80	1.49	1.23	1.15	1.14	3.66	1.89	.52	.66	.81	2.22	.59	16.16
1898	.20	.52	2.39	.56	4.88	3.52	1.71	.71	.87	1.10	.66	.28	17.40
1899	1.60	.53	1.27	.70	1.98	.84	.63	1.26	.64	1.45	.26	.62	11.78
1900	.03	.64	.90	2.49	3.22	.19	.23	.59	1.39	1.21	.30	.43	11.62
1901	.56	.44	1.05	1.58	4.11	1.83	.40	.17	2.63	.07	.16	1.71	14.71

LIVINGSTON, MONT.

Normal	0.60	0.37	0.76	0.59	3.76	1.92	0.75	0.42	1.28	5.83	0.96	0.36	17.60
1896	.37	.10	1.26	.70	2.40	.35	.59	.15	2.37	.83	1.56	T.	10.68
1897	.44	.35	.49	.52	.60	3.30	1.63	T.	.43	1.80	1.66	.55	11.77
1898	T.	.28	1.20	1.04	4.08	4.28	1.28	1.26	.61	1.82	.78	.10	16.08
1899	1.06	1.26	1.20	.50	(3.76)	(1.92)	(.75)	(.42)	(1.28)	(5.83)	.46	1.20	19.64
1900	T.	.14	.44	(.59)	(3.76)	.00	.01	.05	.90	1.20	.03	.40	7.52
1901	(.60)	.01	.05	.77	8.00	1.65	.30	.62	2.10	.25	.23	.94	15.32

Depth of run-off, in inches, from the drainage basin of Middle Creek near Bozeman, Mont.

Year.	Jan.	Feb.	Mar.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898	.....	.....	.....	10.73	11.42	9.79	8.90	8.40	.....	10.14	8.3[illegible]
1899	8.91	9.00	8.91	8.73	11.88	10.01	9.35	8.48	8.61	.....	.....
1900	.....	.....	.....	.....	.....	1.87	1.15	.97	.....	.....	.....
Average	8.91	9.00	8.91	9.73	11.65	7.22	6.47	5.95	8.61	10.14	8.3[illegible]

Depth of run-off, in inches, from the drainage basin of Gallatin River at Logan, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896	0.48	0.44	0.49	0.49	0.77	3.11	0.86	0.49	0.47	0.48	0.47	0.51	9.0[illegible]
1897	.49	.42	.46	.68	2.69	2.00	.49	.32	.36	.44	.47	.46	9.2[illegible]
1898	.09	.06	.46	.71	1.69	3.15	.71	.26	.45	.56	.37	(.49)	9.0[illegible]
1900	.65	.64	.71	.78	2.23	1.55	.23	.24	.33	.43	.48	.45	8.72
Average	.63	.39	.53	.67	1.85	2.45	.57	.33	.40	.48	.45	.48	9.[illegible]

Depth of run-off, in inches, from the drainage basin of Madison River at Red Bluff, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.89	0.80	0.89	1.01	1.85	2.36	1.41	0.93	0.82	0.87	0.90	0.93	13.[illegible]
1898	.....	.....	.....	.....	.....	3.21	2.01	1.48	1.20	1.20	.....	.....	.....
1899	.....	.....	.....	.....	4.49	2.85	1.51	1.15	1.01	.98	.....	.....	.....
1900	.....	.....	.47	.95	2.36	1.93	1.03	.92	.90	1.03	.89	.91	.....
1901	.61	.55	.61	1.05	2.82	1.80	1.12	.86	.79	.82	.81	.....	.....
Average	.75	.68	.66	1.00	2.88	2.43	1.42	1.07	.94	.98	.87	.92	13.[illegible]

Depth of run-off, in inches, from the drainage basin of West Gallatin River at Salesville, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1897	0.33	0.30	0.40	0.75	5.15	3.64	1.76	0.85	0.65	0.70	0.58	0.60	15.71
1898	.81	.97	.75	1.09	3.44	6.02	2.62	1.25	1.04	1.05	.91	1.01	20.96
1899	.93	.84	.90	.94	1.65	7.22	6.12	1.76	1.18	1.14	1.10	1.00	24.78
1900	.81	.60	.67	1.25	4.09	4.23	1.06	.69	.60	.66	.52	.48	15.67
1901	.68	.56	.61	.69	4.89	2.90	1.07	.70	.64	.65	.60	.61	14.60
Average	.71	.63	.67	.94	3.84	4.80	2.53	1.05	1.62	.83	.74	.74	18.24

Depth of run-off, in inches, from the drainage basin of Jefferson River at Sappington, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.20	0.18	0.20	0.41	1.10	0.54	0.30	0.10	0.09	0.12	0.16	0.18	3.58
1898	.20	.18	.17	.44	.77	1.01	.44	.14	.14	.17	.19	.18	4.08
1899	.....	.....	.....	.25	.63	1.36	.80	.25	.16	.21	.25	.11	.....
1900	.....	.....	.....	.38	.83	.50	.13	.07	.09	.17	.19	.20	.....
1901	.....	.....	.....	.29	.89	.47	.15	.07	.08	.10	.13	.....	.....
Average	.20	.18	.19	.35	.84	.78	.36	.13	.11	.15	.18	.17	3.81

Depth of run-off, in inches, from the drainage basin of Missouri River at Townsend, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.22	0.20	0.24	0.55	1.26	0.87	0.43	0.21	0.20	0.26	0.27	0.29	5.00
1898	1.09	1.05	.36	.46	.81	1.41	.49	.18	.20	.24	.....	.....	.....
1899	.....	.....	.....	.....	.77	2.24	1.12	.39	.26	.31	.31	.35	.....
1900	.54	.73	.69	.46	1.09	.73	.17	.14	.16	.22	.29	.29	5.51
1901	.52	.67	.46	.33	1.20	.70	.23	.12	.13	.21	.22	.73	5.52
Average	.59	.66	.44	.45	1.03	1.19	.49	.21	.19	.25	.27	.42	5.34

Rainfall and run-off in Upper Missouri River Basin.

Stations.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Butte	17.88	10.51	15.24	12.37	16.22	14.55	14.55
Fort Logan	12.14	11.61	15.94	16.62	9.57	8.77	15.72
Fort Yellowstone	21.02	20.77	15.62	17.06	25.84	16.73	19.67
Helena	13.65	15.38	16.16	17.40	11.78	11.62	14.71
Livingston	17.60	10.68	11.77	16.08	19.64	7.52	15.32
Average rainfall	16.46	13.79	14.95	15.91	16.61	11.84	15.99

Rainfall and run-off in Upper Missouri River Basin—Continued.

Stations.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RUN-OFF.							
Gallatin at Logan	9.02	9.06	9.28	9.00	.....	8.72	.....
Jefferson at Sappington	3.81	.....	3.58	4.03	.....	.....	.....
Madison at Red Bluff	13.66	.....	13.66	.....	.....	.....	.....
Missouri at Townsend	5.34	5.71	5.00	5.00	.....	5.51	5.52
West Gallatin at Salesville	18.34	17.66	15.71	20.96	.....	15.61	14.60
Average run-off	10.03	5.29	9.45	9.75	.....	9.95	10.06
Percentage of rainfall [a]	60.94	38.36	60.54	61.28	.....	84.05	62.91

[a] This high percentage is probably due to the fact that the rainfall as recorded is that for the lower country, and does not represent the true rainfall on the catchment area.

WEST GALLATIN RIVER.

Estimated monthly discharge of West Gallatin River near Salesville, Mont.

[Drainage area, 860 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	605	455	505	31,051	0.59	0.68
February	495	455	466	26,805	.54	.56
March	475	435	452	27,792	.53	.61
April	700	455	529	31,478	.62	.69
May	7,810	1,230	3,643	223,998	4.24	4.89
June	4,120	1,580	2,233	132,873	2.60	2.90
July	1,440	515	799	49,129	.93	1.07
August	620	495	528	32,465	.61	.70
September	495	475	494	29,395	.57	.64
October	495	475	485	29,821	.56	.65
November	475	435	465	27,669	.54	.60
December	475	455	458	28,161	.53	.61
The year	7,810	435	921	670,637	1.07	14.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 17; rating table on page 170 of same paper.

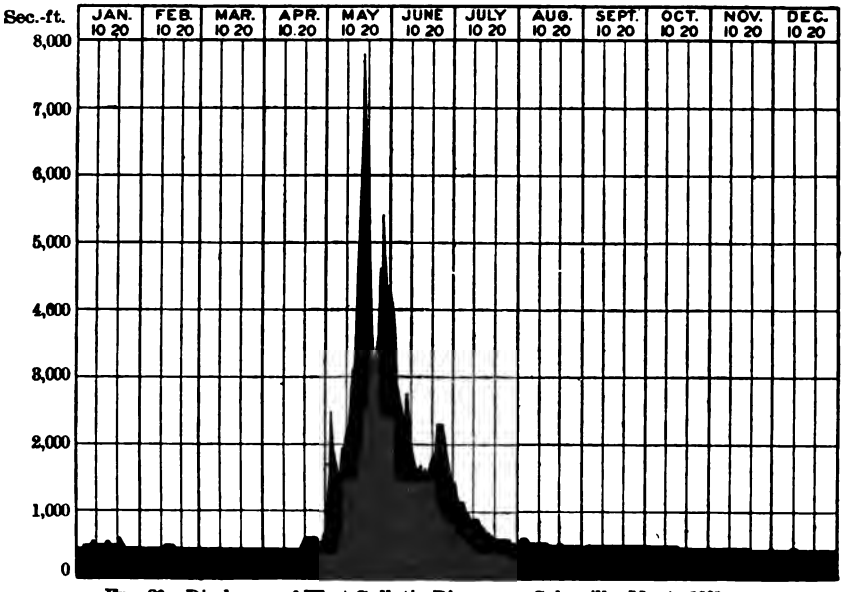


FIG. 36.—Discharge of West Gallatin River near Salesville, Mont., 1901.

MADISON RIVER.

Estimated monthly discharge of Madison River near Red Bluff, Mont.

[Drainage area, 2,085 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 1,106	68,005	0.53	0.61
February			[a] 1,106	61,424	.53	.55
March			[a] 1,106	68,005	.53	.61
April	2,275	1,900	1,958	116,509	.94	1.05
May	8,325	2,825	5,085	312,664	2.44	2.82
June	5,400	2,400	3,357	199,756	1.61	1.80
July	2,400	1,650	2,013	123,774	.97	1.12
August	1,900	1,475	1,560	95,920	.75	.86
September	1,475	1,475	1,475	87,769	.71	.79
October	1,475	1,475	1,475	90,695	.71	.82
November	1,650	1,475	1,516	90,208	.73	.81
December			[a] 1,475	90,695	.71	.82
The year			1,936	1,405,424	.93	12.66

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 19; rating table on page 170 of same paper.

JEFFERSON RIVER.

Estimated monthly discharge of Jefferson River at Sappington, Mont.

[Drainage area, 8,984 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March			1,443	69,491	0.16	0.14
April	5,510	1,260	2,281	135,729	.26	.29
May	9,325	5,730	6,949	427,277	.77	.89
June	7,580	2,375	3,754	223,379	.42	.47
July	2,375	610	1,187	72,986	.13	.15
August	610	550	535	32,896	.06	.07
September	820	430	665	39,570	.07	.08
October	935	820	847	52,080	.09	.10
November	1,155	975	1,057	62,896	.12	.13
December			1,164	43,866	.13	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 19; rating table on page 170 of same paper.

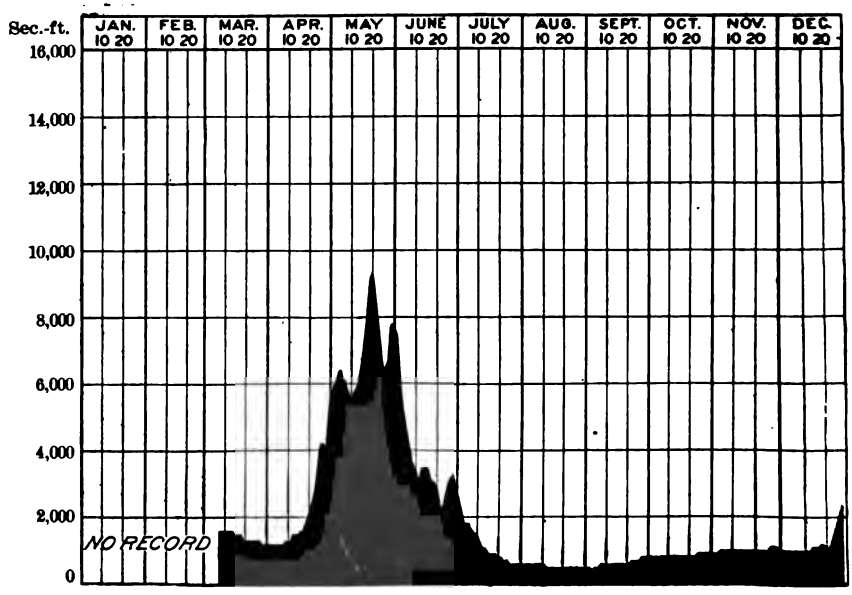


FIG. 37.—Discharge of Jefferson River at Sappington, Mont., 1901.

MISSOURI RIVER.

Estimated monthly discharge of Missouri River near Townsend, Mont.

[Drainage area, 14,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	8,155	1,020	6,579	404,526	0.45	0.52
February	10,220	7,760	9,296	516,273	.64	.67
March	22,880	3,020	5,884	361,793	.40	.46
April	6,635	2,745	4,340	249,639	.30	.33
May	22,150	7,375	15,029	924,097	1.04	1.20
June	19,450	5,600	9,085	540,595	.63	.70
July	5,600	1,590	2,949	181,327	.20	.23
August	1,800	1,390	1,521	93,522	.10	.12
September	2,020	1,200	1,778	105,798	.12	.13
October	3,020	2,250	2,634	161,958	.18	.21
November	3,020	2,745	2,965	176,429	.20	.22
December	18,825	3,020	9,473	563,682	.65	.73
The year	22,880	1,020	5,961	4,279,639	.41	5.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 21; rating table on page 170 of same paper.

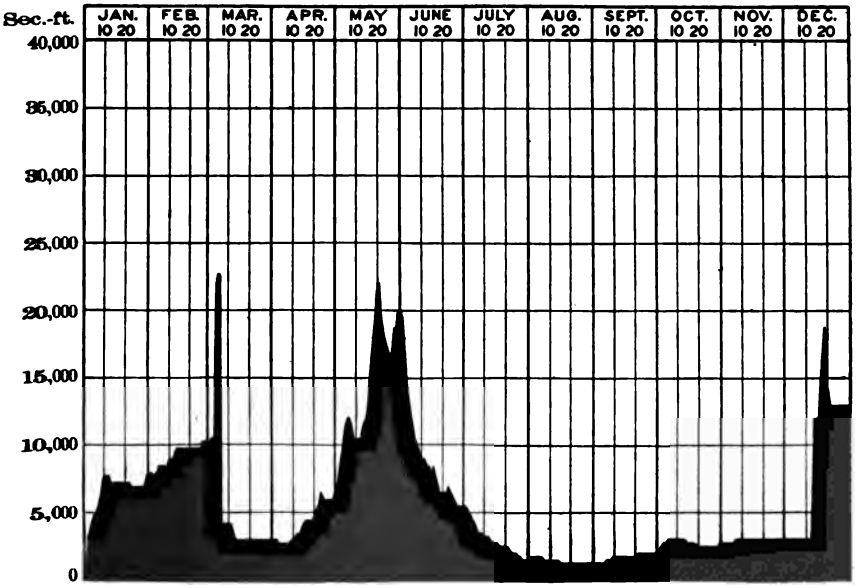


FIG. 38.—Discharge of Missouri River near Townsend, Mont., 1901.

MILK RIVER.

Estimated monthly discharge of Milk River at Havre, Mont.

[Drainage area, 7,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March 10-30			600	36,893	0.082	0.095
April	330	115	205	12,198	.028	.031
May	2,540	230	648	39,844	.089	.103
June	1,340	330	553	32,906	.076	.085
July	460	65	184	11,314	.025	.029
August	65	12	28	1,722	.004	.005
September	95	11	56	3,332	.008	.009
October	95	65	82	5,042	.011	.013
November	95	65	80	4,760	.011	.012

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No 66, page 16; rating table on page 170 of same paper.

YELLOWSTONE RIVER.

Estimated monthly discharge of Yellowstone River near Livingston, Mont.

[Drainage area, 3,580 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 1,100	67,636	0.31	0.36
February			[a] 1,000	55,537	.28	.29
March	1,380	1,000	1,264	77,720	.35	.40
April	2,050	1,265	1,489	88,602	.42	.47
May	26,525	2,665	1,218	74,892	.34	.39
June	13,250	8,230	10,228	608,608	2.86	3.19
July	8,075	3,590	5,534	340,273	1.55	1.79
August	4,400	2,440	3,107	191,042	.87	1.00
September	2,560	2,050	2,248	133,765	.63	.70
October	2,050	1,750	1,926	118,425	.54	.62
November			[a] 1,593	94,790	.45	.50
December			[a] 1,200	73,785	.34	.39
The year			2,659	1,925,075	.75	10.10

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 22; rating table on page 170 of same paper.

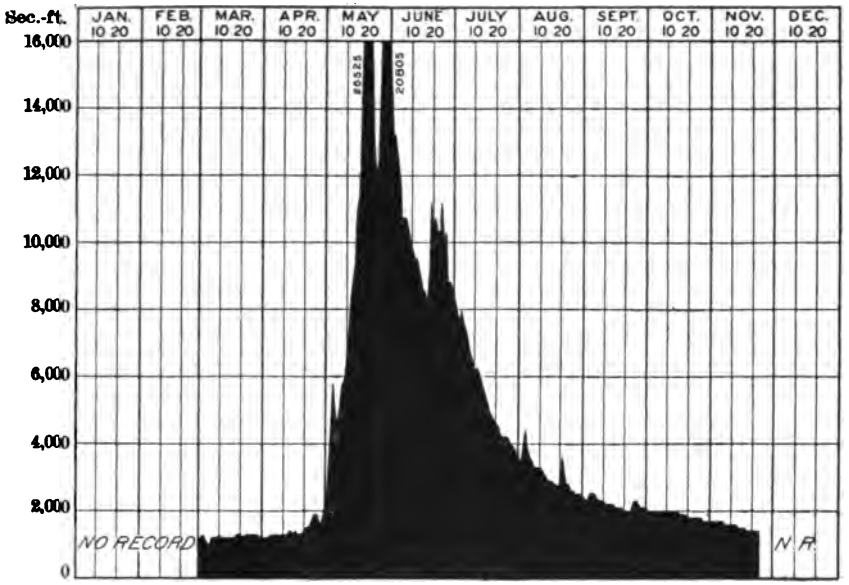


FIG. 39.—Discharge of Yellowstone River near Livingston, Mont., 1901.

Estimated monthly discharge of Bighorn River near Thermopolis, Wyo.

[Drainage area, 8,184 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	17,610	2,980	10,118	622,132	1.24	1.43
June	14,750	5,840	8,739	520,007	1.07	1.19
July	6,830	4,300	5,886	361,916	.72	.83
August	4,410	1,990	2,916	179,298	.36	.42
September	3,530	1,550	2,107	125,376	.26	.29

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 28; rating table on page 170 of same paper.

BIG SIOUX RIVER.

Estimated monthly discharge of Big Sioux River near Sioux Falls, S. Dak.

[Drainage area, 4,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
August 10–31			24	1,047	0.005	.004
September	44	14	26	1,547	.006	.007
October	64	14	45	2,767	.010	.012
November 1–17			50	1,685	.010	.004
1901.						
April 1–20			14	555	.003	.002
May 5–31			97	5,193	.022	.023
June	250	89	168	9,996	.038	.044
July	146	9	44	2,705	.010	.012
August 1–2, 11–31			9	411	.002	.002
September	17	3	14	833	.003	.003
October	21	17	18	1,107	.004	.005
November	31	17	27	1,607	.006	.007

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 24; rating table on page 170 of same paper.

PLATTE RIVER DRAINAGE.

Platte River rises on the eastern slope of the Rocky Mountains in Wyoming, Colorado, and Nebraska. Its headwaters are extensively utilized for irrigation, the most important drainage basin in Colorado being that of South Platte River which traverses a region unequaled in the United States for the extent to which intensive farming has been developed there by irrigation. As in previous years the greater number of river stations maintained in the Platte Basin are located on South Platte River and tributaries in Colorado. New stations were established during the year 1901 at Medicine Bow, Wyo., on Medicine Bow River, a tributary of the North Platte; at Mitchell, Nebr., on North Platte River, and at Kersey, Colo., on South Platte River. The station at Mitchell replaces the one previously maintained at Gering, Nebr., it being situated nearer the Wyoming-Nebraska State line and therefore of greater value in determining the flow at that point. Observations were discontinued at Orchard, Colo., on South Platte River, and the station moved to Kersey, where it is believed better results can be obtained. A detailed report on the

Platte River drainage in Colorado, together with a résumé of all the available records of flow, is contained in Water-Supply Paper No. 74, on the Water Resources of the State of Colorado, by A. L. Fellows.

NORTH PLATTE RIVER.

Estimated monthly discharge of Medicine Bow River at Medicine Bow, Wyo.

[Drainage area, 900 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	1,920	.....	[a] 940	57,798	1.04	1.20
June	1,650	350	977	58,136	1.09	1.22
July	272	45	96	5,903	.11	.12
August	45	6	17	1,045	.02	.02
September	17	8	16	952	.02	.02

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 26; rating table on page 170 of same paper.

Estimated monthly discharge of North Platte River near Guernsey, Wyo.

[Drainage area, 16,243 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	10,435	682	2,066	122,936	0.13	0.15
May	13,217	5,930	8,589	528,117	.53	.61
June	13,880	5,400	9,154	544,701	.56	.62
July	5,532	1,070	1,899	116,765	.12	.14
August	1,070	420	706	43,410	.04	.05
September	420	80	316	18,803	.02	.02

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 27; rating table on page 170 of same paper.

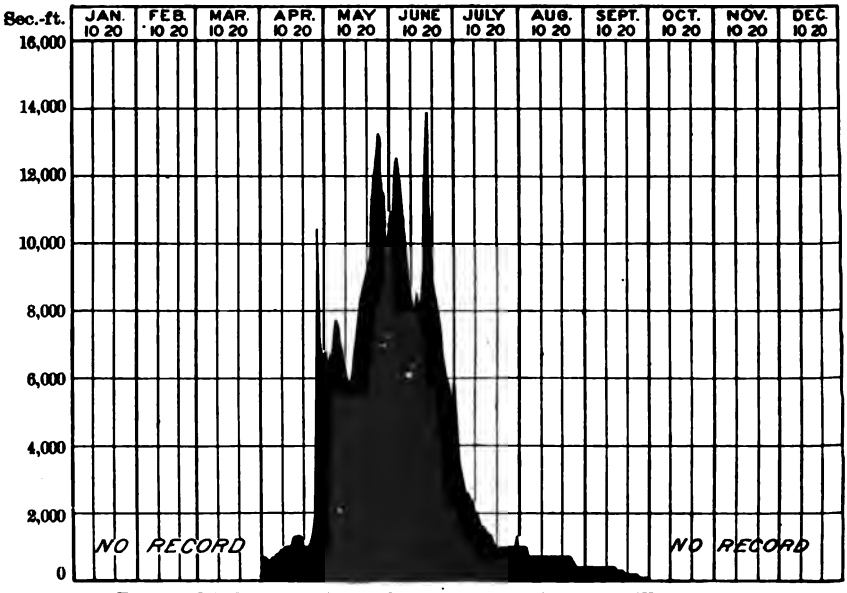


FIG. 40.—Discharge of North Platte River near Guernsey, Wyo., 1901.

Estimated monthly discharge of North Platte River at Mitchell, Nebr.

[Drainage area, 24,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June 9–30			7,514	327,884	0.308	0.252
July 1–20			2,358	96,454	.096	.073
August 12–31			398	16,315	.016	.012
September	422	210	322	19,160	.013	.015
October	520	235	384	23,611	.016	.018

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 28.

SOUTH PLATTE RIVER.

Estimated monthly discharge of South Platte River at Denver, Colo.

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	242	186	212	13,035	0.06	0.07
February	242	186	217	12,052	.06	.06
March	306	213	241	14,818	.07	.08
April	1,121	242	516	30,704	.13	.15
May	1,026	113	553	34,003	.14	.16
June	1,386	113	715	42,545	.19	.21
July	575	25	250	15,310	.07	.08
August	611	242	366	22,443	.10	.12
September	422	51	216	12,853	.06	.07
October	213	25	94	5,657	.02	.02
November	136	12	73	4,284	.02	.02
December	341	113	234	14,388	.06	.07
The year	1,386	12	307	222,092	.08	1.11

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 30; rating table on page 171 of same paper.

Estimated monthly discharge of Bear Creek near Morrison, Colo.

[Drainage area, 170 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	132	11	54	3,213	0.32	0.36
May	168	93	116	7,132	.68	.78
June	187	93	114	6,784	.67	.75
July	96	24	52	3,197	.31	.36
August	190	18	40	2,459	.24	.28
September	51	13	22	1,309	.13	.15
October	29	13	20	1,230	.12	.14
November	21	9	15	893	.09	.10

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 31; rating table on page 171 of same paper.

Estimated monthly discharge of Clear Creek at Forkscreek, Colo.

[Drainage area, 345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May 8–31	.....	.....	[a] 558	34,310	1.62	1.87
June	775	544	652	38,856	1.89	2.11
July	692	235	433	26,624	1.25	1.44
August	367	155	227	14,019	.66	.76
September	179	66	114	6,783	.33	.37
October	93	58	73	4,489	.21	.24
November	58	20	37	2,202	11	.12

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 81; rating table on page 171 of same paper.

Estimated monthly discharge of South Boulder Creek near Marshall, Colo.

[Drainage area, 125 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	119	7	47	2,797	0.38	0.42
May	263	64	128	7,932	1.02	1.18
June	278	193	229	13,627	1.83	2.04
July	220	57	118	7,256	.94	1.08
August	78	34	48	2,951	.38	.44
September	34	18	20	1,190	.16	.18

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 33, rating table on page 171 of same paper.

Estimated monthly discharge of Boulder Creek near Boulder, Colo.

[Drainage area, 179 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	264	6	75	4,463	0.42	0.47
May	705	164	388	23,857	2.17	2.50
June	789	390	513	30,526	2.87	3.20
July	516	191	319	19,615	1.78	2.05
August	225	44	114	7,010	.64	.74
September	70	16	35	2,083	.20	.22
October	32	11	15	922	.08	.09
November	11	6	8	476	.04	.04
December	6	4	5	307	.03	.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 38; rating table on page 171 of same paper.

Estimated monthly discharge of St. Vrain Creek near Lyons, Colo.

[Drainage area, 209 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	253	4	102	6,069	0.49	0.55
May	667	148	337	20,844	1.61	1.86
June	730	304	490	29,157	2.34	2.61
July	478	196	301	18,569	1.44	1.66
August	269	87	157	9,653	.75	.86
September	126	25	59	3,511	.28	.31
October	38	19	30	1,845	.14	.16
November	25	4	14	833	.07	.08

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 35; rating table on page 171 of same paper.

Estimated monthly discharge of Big Thompson Creek near Arkins, Colo.

[Drainage area, 305 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	977	208	600	36,893	1.97	2.27
June	1,143	620	859	51,114	2.82	3.15
July	975	225	530	32,650	1.74	2.01
August	506	140	261	16,048	.86	.99
September	110	44	72	4,284	.24	.27

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 36; rating table on page 171 of same paper.

Estimated monthly discharge of Cache la Poudre River near Fort Collins, Colo.

[Drainage area, 1,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	5,100	619	1,757	108,034	1.66	1.91
June	2,449	1,425	1,956	116,390	1.85	2.06
July 1-23			885	42,129	.83	.74
August	510	242	337	20,721	.32	.37
September	294	98	152	9,045	.14	.16
October 1-15			119	3,540	.11	.06

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 66, page 37.

Estimated monthly discharge of South Platte River at Kersey, Colo.

[Drainage area, 9,470 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	5,856	62	1,393	85,653	0.15	0.17
June	5,004	450	1,820	108,297	.19	.21
July	450	290	314	19,307	.03	.03
August	330	290	296	18,200	.03	.03
September	705	290	395	23,504	.04	.04
October	516	370	456	28,039	.05	.06
November	591	450	526	31,299	.06	.07
December	1,955	540	903	55,524	.10	.12

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 38; rating table on page 171 of same paper.

PRECIPITATION IN THE UPPER BASIN OF SOUTH PLATTE RIVER.

The principal observations of rainfall made within the upper basin of South Platte River are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea

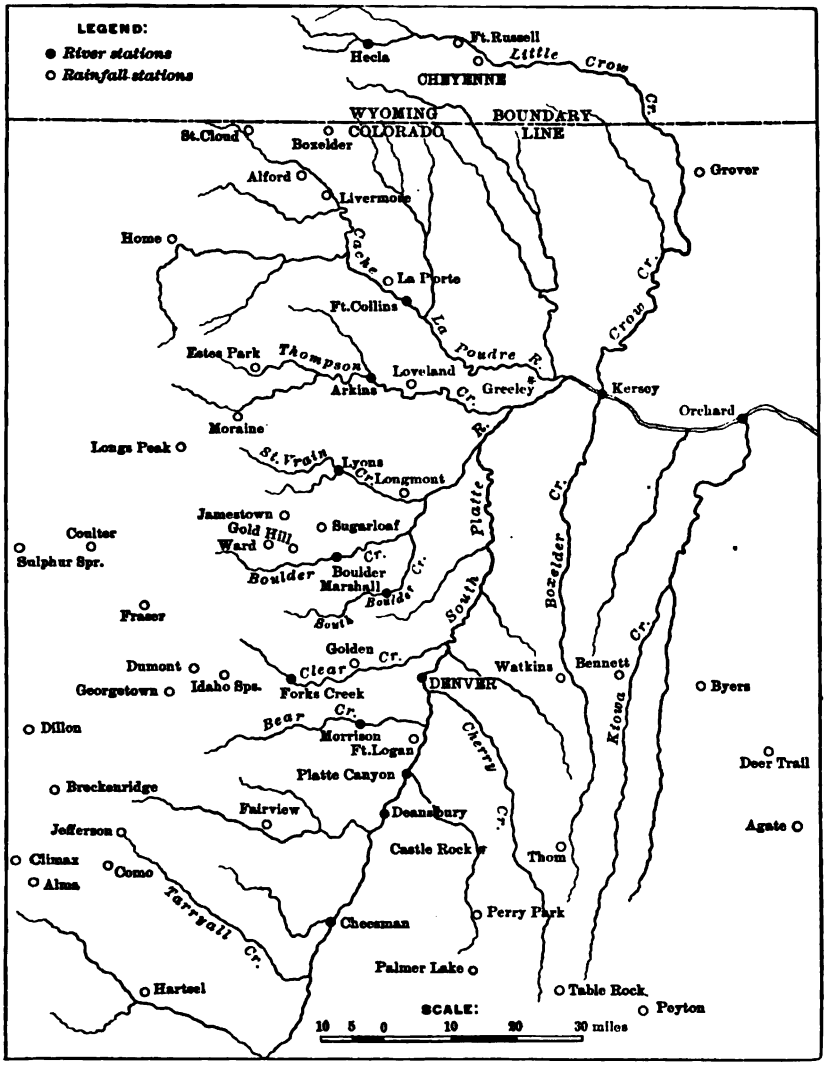


FIG. 41.—Location of rainfall and river stations in the upper basin of South Platte River.

level, and length of record of observations. The relative locations of the points are shown in fig. 41 in connection with the points of river measurement, which are located at Denver, Morrison, Forkscreek, Marshall, Boulder, Lyons, Arkins, Fort Collins, Orchard, and Kersey.

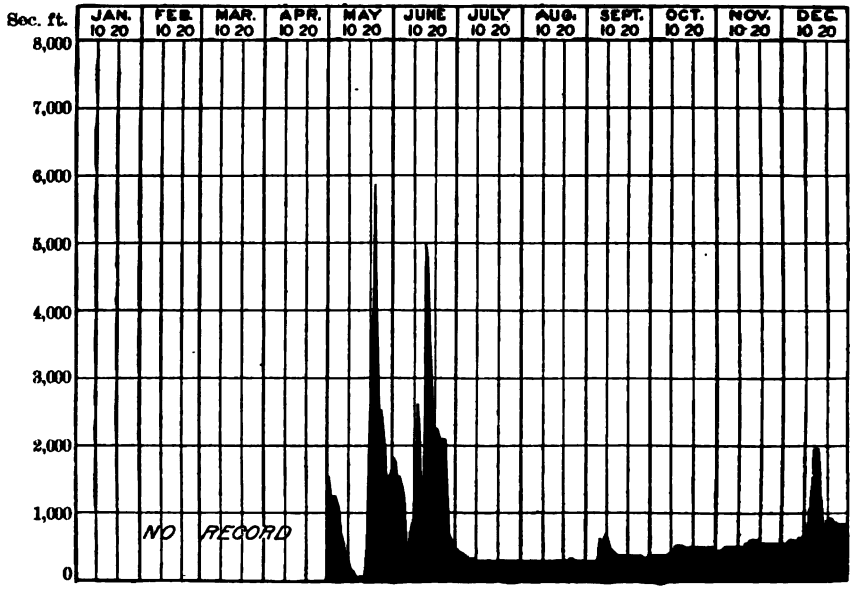


FIG. 42.—Discharge of South Platte River at Kersey, Colo., 1901.

Location of rainfall stations in South Platte River Basin.

Stations.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Boxelder	Larimer	Colorado				10-12
Breckenridge	Summit	do	39 31	106 0	9,524	11-13
Castlerock	Douglas	do				9-12
Cheyenne	Laramie	Wyoming	41 8	104 48		32
Denver	Arapahoe	Colorado	39 45	105 0	5,281	32
Dumont	Clear Creek	do	40 35	105 2	5,000	10-11
Fort Collins	Larimer	do	40 26	104 42	4,750	19-28
Greeley	Weld	do	40 38	105 6		10-13
Laporte	Larimer	do				11-13
Longs Peak	do	do				6-7
Moraine	do	do				11-13
Sugar Loaf	Boulder	do				10-12

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation, by months, for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of South Platte River.

BOXELDER, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.70	0.71	1.36	1.98	3.41	1.64	2.20	2.05	0.96	0.74	0.43	0.56	16.69
1896	.58	.06	3.24	1.10	2.53	2.16	1.98	3.05	2.86	.02	.27	.08	17.83
1897	.18	.65	2.75	2.22	3.49	1.59	4.08	4.31	.68	.84	.83	.85	21.42
1898	.70	.22	.58	1.32	5.62	1.66	1.36	1.71	1.36	.47	1.17	.17	16.34
1899	1.27	1.78	1.42	1.06	.52	1.79	2.23	1.46	.13	2.51	.08	.17	14.42
1900	.18	.86	.62	6.70	4.00	.54	2.72	.55	1.55	.00	.00	.21	17.96
1901	.19	.68	1.62	2.96	4.18	1.89	.57	1.66	.49	.46	.13	2.47	17.25

BRECKENRIDGE, COLO.

Normal	2.06	3.51	3.65	3.28	2.37	1.05	2.34	2.16	0.88	1.43	2.41	2.75	27.89
1896	1.88	1.89	4.83	.60	1.47	.30	3.10	2.29	2.25	.82	3.87	.73	24.08
1897	2.90	1.99	3.53	4.00	1.54	1.53	1.70	2.27	1.16	1.02	.60	2.25	24.49
1898	.29	.59	1.16	1.53	.46	1.14	2.19	1.59	.38	1.53	4.09	1.34	16.29
1899	4.75	5.08	7.94	1.31	.31	1.52	2.29	1.60	.29	2.54	.58	1.20	29.41
1900	.35	2.48	1.06	4.82	1.68	1.12	.33	.74	.30	.60	.44	.70	14.62
1901	2.36	3.02	2.40	3.12	2.87	1.58	.89	4.94	.08	.78	.90	2.86	25.80

CASTLEROCK, COLO.

Normal	0.54	0.81	1.08	2.44	2.41	1.82	2.91	2.47	0.73	1.19	0.50	0.75	17.60
1896	.65	.95	1.80	2.30	1.61	.70	3.67	3.57	2.80	1.62	.32	.45	20.44
1897	.47	1.20	2.50	1.37	(2.41)	3.12	3.59	8.10	.24	2.82	(.50)	1.23	27.55
1898	(.54)	(.81)	.40	1.76	6.48	1.82	4.20	1.49	1.35	1.17	1.00	.99	22.01
1899	.63	.67	.77	1.50	.53	1.10	4.48	2.39	T.	1.30	.17	1.16	14.70
1900	.10	.63	.62	7.90	.55	1.80	1.77	.24	.06	.40	.33	.30	14.70
1901	.25	.30	1.04	3.47	1.82	1.35	1.72	3.45	.50	.28	T.	.59	14.77

CHEYENNE, WYO.

Normal	0.39	0.50	0.87	1.64	2.24	1.52	1.96	1.46	0.94	0.68	0.35	0.35	12.90
1896	.68	.31	2.06	2.08	2.85	1.41	6.35	2.52	2.08	.28	.14	.03	20.79
1897	.27	.57	2.32	.60	3.07	1.60	3.77	1.66	.41	1.03	.68	1.27	17.25
1898	.48	.06	.37	.68	3.72	2.33	1.83	.90	.47	.25	1.58	.36	13.05
1899	1.23	1.63	1.89	.97	1.70	.74	3.38	1.15	.07	1.27	.07	.18	14.18
1900	.15	1.25	.72	7.66	.76	1.01	1.20	.70	2.19	.03	.07	.33	16.09
1901	.13	1.10	1.54	2.97	2.47	1.98	1.34	.83	.75	.31	T.	1.62	14.99

DENVER, COLO.

Normal	0.55	0.54	0.93	2.10	2.56	1.33	1.56	1.33	0.83	0.87	0.63	0.66	13.89
1896	.25	.24	1.43	.93	1.27	.89	2.80	.97	1.81	.84	.10	.31	11.84
1897	.58	.82	.90	1.31	3.15	2.16	2.06	1.44	.44	1.64	.24	.63	15.37
1898	.20	.68	.28	1.20	4.88	.94	.67	.96	.28	1.05	.85	.99	12.98
1899	.65	.58	1.10	.75	.15	.47	1.92	1.78	.20	1.01	T.	.72	9.33
1900	.13	.55	.63	8.24	.53	1.87	1.30	.05	.87	.33	.37	.42	15.29
1901	.05	.06	.88	1.96	1.18	2.09	.01	1.30	.22	.46	T.	.89	9.10

Precipitation at stations in drainage basin of South Platte River—Continued.

DUMONT, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.32	0.97	1.39	2.45	3.04	1.60	2.58	2.19	1.14	1.39	0.73	0.78	18.58
1896	.25	.45	2.48	1.22	1.15	.58	2.18	2.81	2.04	.78	.50	.60	15.01
1897	.45	.55	2.00	1.43	3.75	1.71	2.55	2.59	1.42	3.32	.20	.85	20.82
1898	.10	.90	.65	2.45	3.20	2.60	1.67	2.60	.48	.40	1.89	.82	17.76
1899	.60	1.34	2.40	1.45	.62	.76	3.60	2.00	.60	3.55	.42	.85	18.19
1900	.09	1.21	.76	9.23	1.02	2.33	1.37	.75	1.25	.82	.19	.52	19.54
1901	.45	.79	1.22	2.79	2.78	1.15	(2.58)	(2.19)	(1.14)	(1.39)	(.73)	(.78)	17.97

FORT COLLINS, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.61	0.58	0.96	2.21	2.99	1.61	1.88	1.21	0.96	0.94	0.38	0.35	14.68
1896	.43	.03	1.73	1.26	1.68	3.05	3.05	2.20	1.55	.49	.05	.24	15.76
1897	.18	.54	2.15	1.39	2.06	1.69	2.65	1.74	.75	.75	.67	.67	15.24
1898	.14	.08	.50	1.08	3.65	1.37	.50	.98	.50	.82	1.24	.17	11.03
1899	.66	1.04	1.50	1.10	1.01	1.03	4.95	.99	.21	3.23	T.	.47	16.19
1900	.25	1.12	1.07	10.56	1.75	.82	1.14	.16	1.92	.24	.07	.11	19.21
1901	.19	.38	1.88	3.62	7.47	2.35	.71	.57	2.25	.36	.02	1.37	21.17

GREELEY, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.27	0.46	0.67	1.94	2.22	1.42	1.79	0.96	0.56	0.79	0.55	0.29	11.92
1896	.67	.18	.93	1.18	1.42	.46	4.82	2.15	.99	.63	.02	.07	13.52
1897	.06	.61	2.02	.81	3.20	2.47	2.98	1.75	.29	1.11	.40	.38	16.09
1898	.20	.33	.23	(1.94)	5.83	1.69	3.50	.83	.13	.78	.60	.37	16.43
1899	1.14	.69	.71	.70	1.15	.47	2.34	1.04	.30	1.85	T.	.40	10.79
1900	.16	.58	.62	6.32	.96	.31	1.28	T.	1.07	.11	.04	.16	11.61
1901	.22	.45	.95	2.12	2.38	2.45	.26	.47	1.06	.75	.05	1.06	12.22

LAPORTE, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.55	0.72	1.26	2.11	2.94	1.55	1.61	1.28	1.00	0.71	0.41	0.57	14.71
1896	.60	.30	2.70	1.00	2.25	2.59	2.47	1.40	1.27	.50	.01	.40	15.49
1897	.20	.50	2.15	1.62	3.35	1.80	2.51	1.14	2.05	.60	1.10	.70	17.72
1898	.45	.10	.45	.24	5.00	1.27	.67	1.72	.55	.88	1.90	.40	13.63
1899	.89	1.08	1.81	.80	.88	.71	2.62	.95	.18	3.02	.00	.40	13.34
1900	.84	1.47	.79	10.02	1.84	.59	1.75	1.20	1.58	.25	.05	.23	20.06
1901	.05	.27	1.42	4.28	4.32	2.41	.57	.87	.97	.05	.01	1.51	16.73

LONGS PEAK, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.45	0.85	1.74	2.28	1.27	1.47	2.67	1.63	1.06	1.46	0.61	0.54	16.03
1896	.26	.55	3.17	1.00	1.21	.65	3.60	2.95	1.95	1.05	.37	.15	16.91
1897	.78	1.25	1.96	1.45	1.60	1.50	1.85	1.29	.95	1.41	1.07	.55	15.66
1898	.24	.83	.75	1.73	2.07	2.06	2.94	1.53	.81	.60	1.60	.60	15.76
1899	.54	1.15	3.01	1.18	.38	1.09	4.32	1.73	.11	2.50	.02	.64	16.67
1900	.16	.85	.35	6.34	.60	.80	.51	.17	1.93	1.14	.44	.64	13.93
1901	.69	.47	1.19	1.97	1.73	1.47	.85	2.22	1.59	.95	.18	1.00	14.31

Precipitation at stations in drainage basin of South Platte River—Continued.

MORAINE, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.70	1.42	1.69	2.21	2.66	1.21	2.20	1.81	1.02	1.06	0.70	0.72	17.40
1896	.53	.22	2.87	1.08	1.62	.49	3.88	2.50	2.74	.75	.30	.30	17.28
1897	.61	1.68	1.86	1.29	2.30	1.79	2.52	2.43	.78	1.16	1.25	1.20	18.87
1898	.50	1.05	1.32	1.44	3.05	1.93	2.19	1.67	.40	.99	1.77	.55	16.86
1899	.77	2.32	2.98	1.39	.45	1.57	3.02	1.32	.15	1.96	.00	.65	16.58
1900	.21	1.11	.80	7.74	1.30	.91	.36	.23	2.19	1.42	.47	.48	16.72
1901	.61	.72	1.06	2.36	3.32	1.52	1.43	2.65	.42	.38	.27	1.15	15.89

SUGAR LOAF, COLO.

Normal	1.01	1.32	3.16	2.62	3.85	2.04	2.97	2.75	1.30	1.52	1.17	1.07	24.78
1896	1.10	.40	3.60	1.60	1.15	1.69	3.56	4.45	1.92	1.40	.30	.20	21.37
1897	.40	2.10	6.30	2.81	(3.85)	3.80	3.65	3.91	1.95	3.85	.80	.70	34.12
1898	.90	.90	.80	3.36	3.95	3.51	2.93	2.78	1.30	1.35	2.17	1.18	25.13
1899	1.20	1.22	5.29	1.59	1.11	.74	2.83	3.98	.60	(1.52)	(1.17)	(1.07)	22.32
1900	(1.01)	(1.32)	(3.16)	(2.62)	(3.85)	.95	1.97	1.12	2.97	.60	.20	.97	20.74
1901	.84	.33	2.17	5.60	3.60	2.20	2.80	4.90	.50	.66	.12	1.40	25.12

Depth of run-off, in inches, from the drainage basin of Bear Creek near Morrison, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	1.02	1.15	0.78	1.35	0.44	0.37	0.22	0.14
1898	.....	.74	.98	1.01	.45	.30	.20	.16	.....
1899	.....	.70	.61	.59	.70	.20	.....	.....	.....
1900	.....	3.30	2.49	.78	.33	.....	.20	.11	.....
1901	0.36	.78	.75	.36	.28	.15	.14	.10	.....
Average	.36	1.31	1.19	.70	.62	.27	.23	.15	.14

Depth of run-off, in inches, from the drainage basin of Big Thompson Creek at Arkins, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	1.58	1.68	1.00	0.49	0.13	0.07	0.10	0.15
1898	.....	.62	1.38	.90	.29	.11	.04	.02	.....
1899	0.52	1.14	3.36	2.47	1.07	.33	.24	.....	.....
1900	1.51	5.22	4.94	1.31	.52	.28	.....	.....	.....
1901	.....	2.27	3.15	2.01	.99	.27	.....	.....	.....
Average	1.02	2.17	2.90	1.54	.67	.22	.12	.06	.15

Depth of run-off, in inches, from the drainage basin of Boulder Creek near Boulder, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.09	2.86	2.18	1.37	0.52	0.30	0.23	0.39
1898	.....	1.50	2.79	1.37	.40	.19	.05	.24	.....
1899	0.72	2.27	4.13	3.71	1.71	.55	.25	.14	.....
1900	.....	.76	6.99	2.87	1.06	.60	.37	.....	.....
1901	.47	2.50	3.20	2.05	.74	.22	.09	.04	.08
Average	.60	1.82	3.99	2.44	1.06	.42	.21	19	.22

Depth of n-off, in inches, from the drainage basin of South Platte River at Kersey, Colo.

Year.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	0.17	0.21	0.03	0.03	0.04	0.06	0.07	0.12
Average	.17	.21	.03	.03	.04	.06	.07	.12

Depth of run-off, in inches, from the drainage basin of St. Vrain Creek near Lyons, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.82	3.56	2.53	1.51	0.65	0.24	0.19	0.22
1898	.....	1.16	2.30	1.27	.58	.32	.08	.07	.....
1899	1.15	1.43	3.95	3.59	1.65	.46	.22	1.11	.....
1900	.....	3.50	3.32	1.49	.54	.36	.25	.....	.....
1901	.55	1.86	2.61	1.66	.86	.31	.16	.08	.....
Average	.85	2.15	3.15	2.11	1.06	.42	.19	.36	.22

Depth of run-off, in inches, from the drainage basin of South Boulder Creek near Marshall, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.82	3.58	2.17	1.19	0.38	0.36	0.31	0.2[illegible]
1898	.....	1.79	2.54	1.27	.39	.20	.18	.16	.....
1899	1.02	2.56	3.72	2.24	.84	.31	.....	.....	.....
1900	.....	.....	3.18	.85	.27	.08	.....	.....	.....
1901	.42	1.18	2.04	1.08	.44	.18	.....	.....	.....
Average	.72	2.09	3.01	1.52	.63	.23	.27	.24	.2[illegible]

Depth of run-off, in inches, from the drainage basin of South Platte River at Denver, Colo.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1897	0.03	0.02	0.05	0.14	0.22	0.30	0.12	0.21	0.08	0.08	0.12	0.06	1.4[illegible]
1898	.04	.04	.03	.11	.44	.45	.21	.10	.06	.04	.03	.03	1.5[illegible]
1899	.02	.05	.12	.13	.13	.23	.20	.16	.08	.03	.59	.04	1.[illegible]
1900	.06	.05	.06	.48	1.26	.81	.12	.05	.03	.03	.06	.06	[illegible]
1901	.07	.06	.08	.15	.16	.21	.08	.12	.07	.02	.02	.07	1.[illegible]
Average	.04	.04	.07	.20	.44	.40	.15	.13	.06	.04	.16	.05	1.[illegible]

Depth of run-off, in inches, from the drainage basin of South Platte River at Orchard, Colo.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1896	0.072	0.026	0.054	.....	.....	.....	.....	.....	.....	.....	.....	0.074	.....
1897	.059	.047	.013	0.048	0.084	0.240	0.082	0.075	0.009	0.029	0.100	.115	0.[illegible]
1898	.100	.730	.070	.030	.180	.080	.010	.030	.010	.020	.080	.250	1.[illegible]
1899	.280	.280	.220	.120	.044	.110	.150	.071	.004	.040	.072	.150	1.[illegible]
1900	.150	.100	.070	.380	.810	.420	.010	.010	.010	.050	.060	.060	2.[illegible]
Average	.132	.237	.085	.145	.255	.212	.051	.047	.008	.035	.078	.130	1.[illegible]

Rainfall and run-off, South Platte River Basin.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Boxelder	16.69	17.83	21.42	16.34	14.42	17.93	17.25
Breckenridge	27.89	24.03	24.49	16.29	29.41	14.62	25.80
Castlerock	17.60	20.44	27.55	22.01	14.70	14.70	14.77
Cheyenne	12.90	20.79	17.25	13.05	14.18	16.09	14.99
Denver	13.89	11.84	15.37	12.98	9.33	15.29	9.10
Dumont	18.58	15.01	20.82	17.76	18.19	19.54	17.97
Fort Collins	14.68	15.76	15.24	11.03	16.19	19.21	21.17
Greeley	11.92	13.52	16.09	16.43	10.79	11.61	12.22
Laporte	14.71	15.49	17.72	13.63	13.34	20.06	16.73
Longs Peak	16.03	16.91	15.66	15.76	16.67	13.93	14.31
Moraine	17.40	17.28	18.87	16.86	16.58	16.72	15.89
Sugar Loaf	24.78	21.37	34.12	25.13	22.32	20.74	25.12
Average	17.26	17.52	20.38	16.44	16.34	16.70	17.11
RUN-OFF.[a]							
South Platte at Denver	1.790	.....	1.430	1.580	1.780	3.070	1.110
South Platte at Orchard	1.528	.....	.851	1.590	1.541	2.130	.....
Average	1.659	.....	1.141	1.585	1.660	2.600	1.110
Percentage of rainfall	9.61	.....	5.60	9.64	10.16	15.57	6.49

[a] This represents only the excess water over the demands for irrigation, together with the return or seepage waters.

LOUP RIVER.

Estimated monthly discharge of Loup River near Columbus, Nebr.

[Drainage area, 13,542 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	4,681	2,573	3,254	193,626	0.24	0.27
May	2,743	1,847	2,346	144,250	.17	.20
June	5,902	1,723	3,467	206,300	.26	.29
July	3,048	([a])	1,609	98,934	.12	.14
August	1,825	([a])	1,377	84,668	.10	.12
September	4,776	1,763	2,853	169,765	.21	.23
October	2,647	1,898	2,243	137,916	.17	.20
November	3,367	1,743	2,325	138,942	.17	.19

[a] On account of shifting of the bed of the river the low-water flow is somewhat uncertain.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 38.

PLATTE RIVER.

Estimated monthly discharge of Platte River near Columbus, Nebr.

[Drainage area, 56,867 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	28,400	1,300	8,827	525,243	0.16	0.18
May	9,200	2,054	5,300	325,884	.09	.10
June	12,875	5,500	9,363	557,137	.16	.18
July 1-11			1,991	47,389	.04	.02
August	0	0	0	0	.00	.00
September	0	0	0	0	.00	.00
October	0	0	0	0	.00	.00
November	978	375	672	40,641	.01	.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 39.

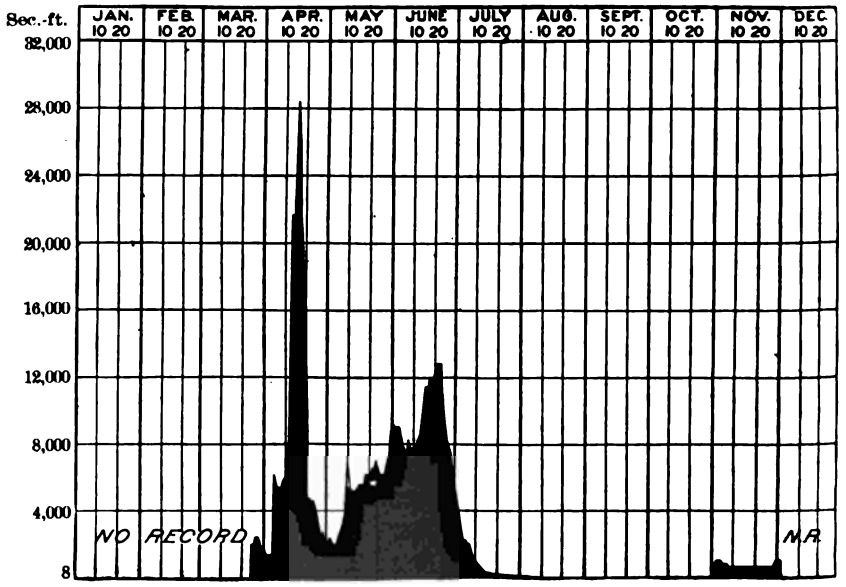


FIG. 43.—Discharge of Platte River near Columbus, Nebr., 1901.

ELKHORN RIVER.

Estimated monthly discharge of Elkhorn River near Norfolk, Nebr.

[Drainage area, 2,474 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	933	431	648	38,559	0.26	0.29
May	881	306	489	30,067	.20	.23
June	3,438	270	1,271	75,630	.51	.57
July	2,003	215	765	47,038	.31	.35
August	231	149	172	10,576	.07	.08
September	362	142	269	16,006	.11	.12
October	342	308	323	19,860	.13	.15
November	357	319	332	19,755	.13	.15

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 40; rating table on page 171 of same paper.

Estimated monthly discharge of Elkhorn River near Arlington, Nebr.

[Drainage area, 5,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,335	833	1,065	63,372	0.18	0.20
May	2,133	613	1,136	69,850	.19	.22
June	4,745	541	1,869	111,213	.31	.35
July	3,989	544	1,373	84,422	.23	.27
August	533	317	421	25,886	.07	.08
September	705	300	514	30,585	.09	.10
October	679	544	599	36,831	.10	.12
November	726	537	627	37,309	.10	.11

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 41.

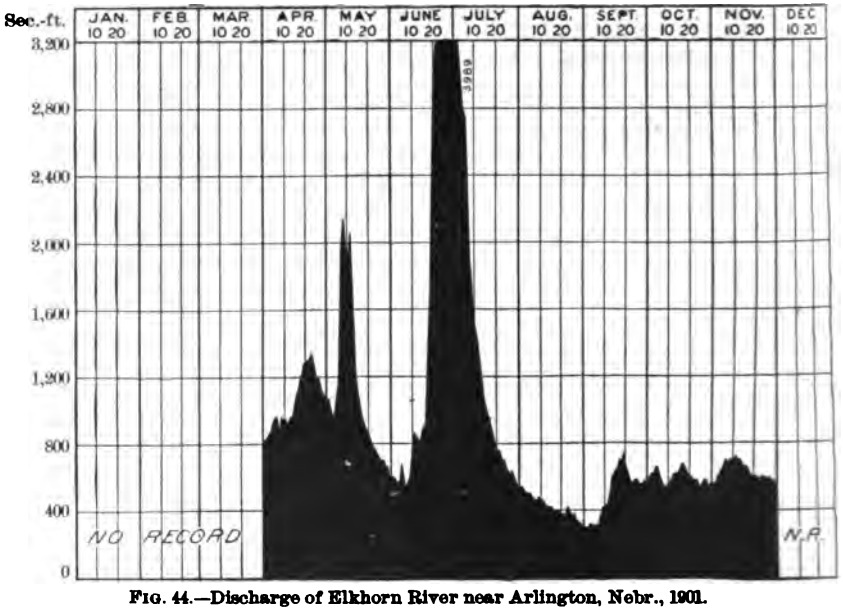


FIG. 44.—Discharge of Elkhorn River near Arlington, Nebr., 1901.

KANSAS RIVER DRAINAGE.

As in previous years systematic measurements were carried on during 1901 at seven points in the basin of Kansas River, the main river being gaged at Lecompton, Kans., and its principal tributaries being gaged at or near their mouths. Kansas River is the largest river which rises in the region of the Great Plains and presents together with its numerous tributaries a typical example of Great Plains drainage.

REPUBLICAN RIVER.

Estimated monthly discharge of Republican River near Superior, Nebr.

[Drainage area, 22,347 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,507	637	961	57,183	0.043	0.048
May	622	146	364	22,381	.016	.018
June	480	117	219	13,031	.010	.011
July	154	5	44	2,618	.002	.002
August	856	5	70	4,304	.003	.003
September	4,991	10	1,246	74,142	.056	.062
October	1,490	285	443	27,239	.020	.020
November	1,030	312	419	24,932	.019	.021

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 41; rating table on page 171 of same paper.

Estimated monthly discharge of Republican River at Junction, Kans.

[Drainage area, 25,837 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	570	405	510	31,359	0.020	0.023
February	1,015	450	669	37,154	.026	.027
March	1,750	850	1,030	63,332	.040	.046
April	5,010	930	1,530	91,041	.059	.066
May	1,015	405	747	45,931	.029	.033
June	510	315	406	24,159	.016	.018
July	450	75	177	10,883	.007	.008
August	110	20	53	3,259	.002	.002
September	3,160	20	906	53,911	.036	.040
October	770	405	564	34,679	.022	.025
November	510	405	472	28,086	.018	.020
December	660	450	594	36,524	.023	.027
The year	5,010	20	638	460,318	.025	.335

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 43; rating table on page 171 of same paper.

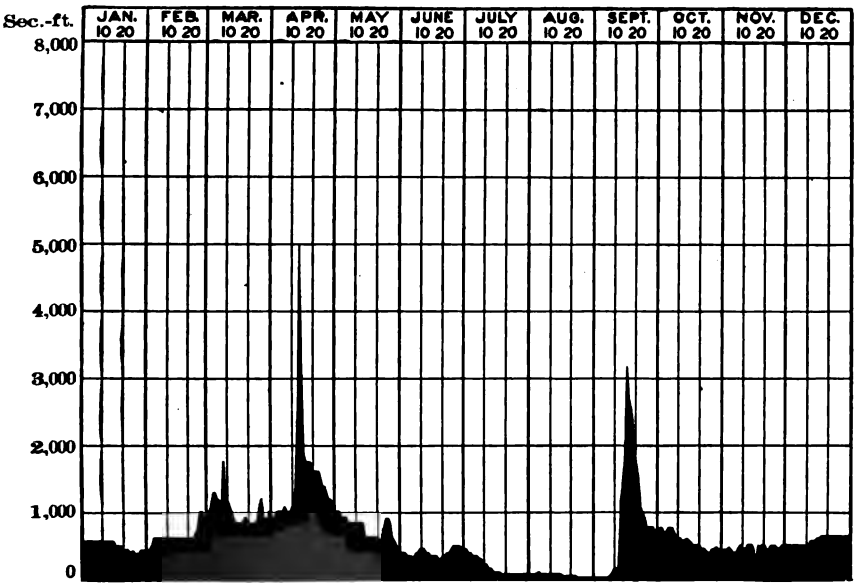


FIG. 45.—Discharge of Republican River at Junction, Kans., 1901.

SOLOMON RIVER.

Estimated monthly discharge of Solomon River near Niles, Kans.

[Drainage area, 6,815 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	114	46	91	5,595	0.013	0.015
February	193	54	90	4,998	.013	.014
March	341	100	152	9,346	.022	.025
April	2,020	114	452	26,896	.066	.074
May	303	89	142	8,731	.021	.024
June	989	46	157	9,342	.023	.026
July	54	7	27	1,660	.004	.005
August	62	7	18	1,107	.003	.003
September	1,604	70	243	14,460	.036	.040
October	89	38	67	4,120	.010	.012
November	176	38	99	5,891	.015	.017
December	100	54	79	4,858	.012	.014
The year	2,020	7	135	97,004	.020	.269

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 44; rating table on page 172 of same paper.

SALINE RIVER.

Estimated monthly discharge of Saline River near Salina, Kans.

[Drainage area, 3,811 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	71	47	56	3,443	0.017	0.020
February	115	55	74	4,110	.022	.023
March	122	51	76	4,673	.023	.027
April	3,580	85	470	27,967	.142	.158
May	315	60	112	6,887	.034	.039
June	2,680	37	376	22,374	.114	.127
July	51	22	31	1,906	.009	.010
August	153	25	47	2,890	.014	.016
September	85	40	53	3,154	.016	.018
October	60	37	47	2,890	.014	.016
November	65	40	53	3,154	.016	.018
December	65	47	57	3,505	.017	.020
The year	3,580	22	121	86,953	.036	.492

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 45; rating table on page 172 of same paper.

SMOKY HILL RIVER.

Estimated monthly discharge of Smoky Hill River at Ellsworth, Kans.

[Drainage area, 7,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	120	18	50	3,074	0.006	0.007
February	165	20	72	3,999	.009	.009
March	50	20	33	2,029	.004	.005
April	662	23	124	7,378	.016	.018
May	81	23	47	2,890	.006	.007
June	142	23	48	2,856	.006	.007
July	18	5	9	553	.001	.001
August	142	5	46	2,828	.006	.007
September	142	12	62	3,689	.008	.009
October	73	14	36	2,214	.005	.006
November	14	8	11	655	.001	.001
December	50	12	22	1,353	.003	.003
The year	652	5	47	33,518	.006	.080

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 45; rating table on page 172 of same paper.

BLUE RIVER.

Estimated monthly discharge of Blue River near Manhattan, Kans.

[Drainage area, 9,490 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	815	522	682	41,935	0.07	0.08
February	4,082	635	1,471	81,695	.16	.17
March	3,013	770	1,129	69,420	.12	.14
April	13,155	1,010	2,146	127,696	.23	.26
May	2,325	725	1,152	70,834	.12	.14
June	1,500	460	828	49,269	.09	.10
July	770	305	473	29,084	.05	.06
August	2,800	380	775	47,653	.08	.09
September	1,010	305	511	30,407	.05	.06
October	590	380	470	28,899	.05	.06
November	1,325	460	590	35,107	.06	.07
December	680	380	498	30,621	.05	.06
The year	13,155	305	894	642,620	.09	1.29

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 46; rating table on page 172 of same paper.

KANSAS RIVER.

Estimated monthly discharge of Kansas River at Lecompton, Kans.

[Drainage area, 58,550 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,375	1,210	1,772	108,956	0.03	0.03
February	8,820	1,210	3,142	174,497	.05	.05
March	11,110	4,465	6,353	390,631	.11	.13
April	25,000	4,332	12,844	764,271	.22	.25
May	7,005	2,625	4,767	293,111	.08	.09
June	4,465	2,375	3,231	192,258	.06	.07
July	2,625	275	1,123	69,051	.02	.02
August	4,465	275	2,173	133,613	.04	.05
September	6,710	2,375	4,367	259,855	.07	.08
October	5,000	445	2,270	139,577	.04	.05
November	1,885	275	1,222	72,714	.02	.02
December	1,000	625	805	49,498	.01	.01
The year	25,000	275	3,672	2,648,032	.06	.85

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 46; rating table on page 172 of same paper.

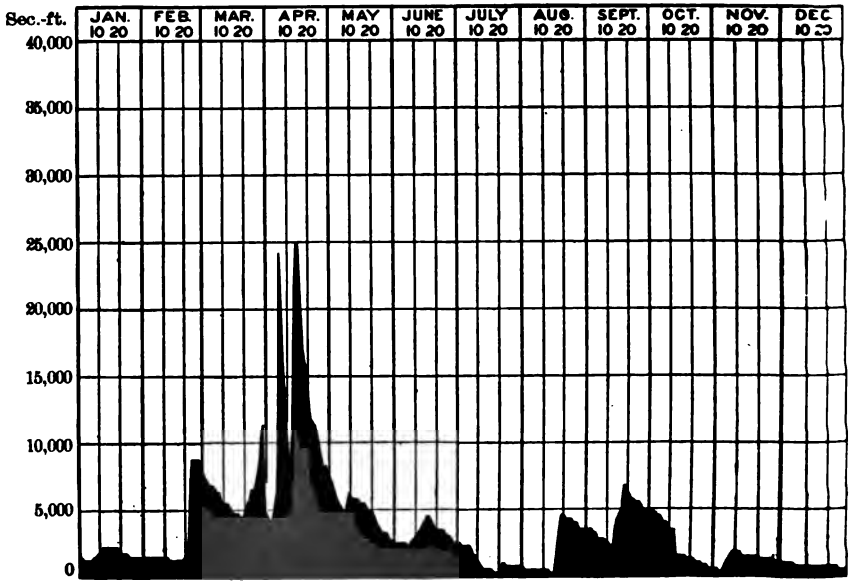


FIG. 46.—Discharge of Kansas River at Lecompton, Kans., 1901.

ARKANSAS RIVER DRAINAGE.

Arkansas River rises in the central portion of Colorado, its headwaters having their source near the summit of the Rockies. The river derives the greater part of its flow from the mountainous regions of Colorado, its volume diminishing greatly as it approaches the level of the plains through constant diversion for irrigation purposes. By far the greater number of gaging stations maintained in the Arkansas River Basin are located in the irrigation districts of Colorado. During 1901 a station was established near Barton, Colo., a few miles west of the Kansas line, the records of which will be of value in determining the amount of water passing from Colorado into Kansas. As in previous years, stations were maintained in Kansas on the Arkansas proper at Hutchinson, on Verdigris River near Liberty, and on Neosho River near Iola. A detailed report on the Arkansas River drainage in Colorado, together with a résumé of all the available records of flow, is contained in Water-Supply Paper No. 74, on the Water Resources of the State of Colorado, by A. L. Fellows.

ARKANSAS RIVER.

Estimated monthly discharge of Arkansas River near Canyon, Colo.

[Drainage area, 3,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	663	217	373	22,195	0.12	0.13
May	3,799	442	1,681	103,300	.55	.63
June	2,633	1,690	2,182	129,938	.71	.79
July	1,912	407	795	48,883	.26	.30
August	1,967	407	630	38,737	.21	.24
September	715	270	352	20,945	.12	.13
October	377	270	313	19,246	.10	.12

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 49; rating table on page 172 of same paper.

Estimated monthly discharge of Arkansas River at Pueblo, Colo.

[Drainage area, 4,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	625	430	474	29,145	0.10	0.12
February	430	254	414	22,992	.09	.09
March	380	254	322	19,799	.07	.08
April	932	234	547	32,549	.12	.13
May	11,060	625	1,784	109,694	.39	.41
June	4,326	1,660	2,347	139,656	.51	.56
July	2,662	338	1,004	61,733	.22	.25
August	1,560	430	776	47,714	.17	.20
September	1,367	214	429	25,527	.09	.10
October	430	254	321	19,737	.07	.08
November	430	254	328	19,517	.07	.08
December	698	296	447	27,485	.10	.11
The year	11,060	214	803	555,548	.17	2.21

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 50; rating table on page 172 of same paper.

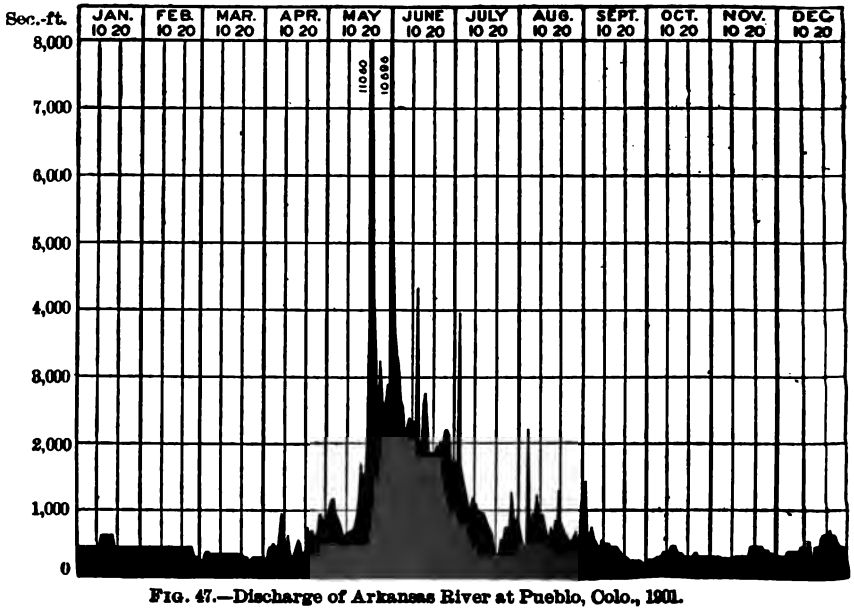


FIG. 47.—Discharge of Arkansas River at Pueblo, Colo., 1901.

Estimated monthly discharge of Arkansas River at Prowers, Colo.

[Drainage area, 19,180 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	120	36	60	3,689	0.003	0.003
February	103	25	64	3,554	.003	.003
March	50	25	40	2,460	.002	.002
April	61	15	41	2,440	.002	.002
May	2,546	48	564	34,679	.029	.033
June	6,086	120	2,129	126,684	.111	.124
July	658	36	176	10,822	.009	.010
August	2,782	48	518	31,851	.027	.031
September	658	10	120	7,140	.006	.007
October	88	10	46	2,828	.002	.002
November	88	36	59	3,510	.003	.003
December	120	25	55	3,382	.003	.003
The year	6,086	10	323	233,039	.017	.223

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 58; rating table on page 172 of same paper.

Estimated monthly discharge of Arkansas River at Hutchinson, Kans.

[Drainage area, 34,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	140	80	94	5,780	0.003	0.003
February	530	80	167	9,275	.005	.005
March	295	140	171	10,514	.005	.006
April	960	140	375	22,314	.011	.012
May	190	100	146	8,977	.004	.005
June	2,820	100	747	44,450	.022	.025
July	205	30	83	5,103	.002	.002
August	60	20	27	1,660	.001	.001
September	205	20	64	3,808	.002	.002
October	140	45	76	4,673	.002	.002
November	52	37	39	2,321	.001	.001
December	70	37	45	2,767	.001	.001
The year	2,820	20	169	121,642	.005	.065

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 56; rating table on page 172 of same paper.

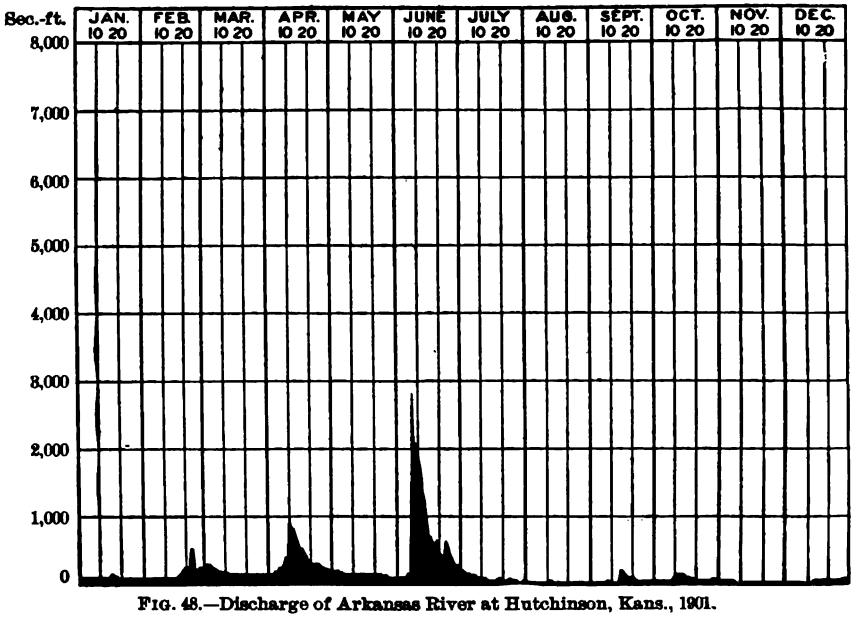


FIG. 48.—Discharge of Arkansas River at Hutchinson, Kans., 1901.

VERDIGRIS RIVER.

Estimated monthly discharge of Verdigris River near Liberty, Kans.

[Drainage area, 3,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	860	280	465	28,592	0.151	0.174
February	2,200	368	920	51,094	.300	.312
March	7,458	368	1,006	61,857	.328	.379
April	16,260	760	3,272	194,697	1.067	1.195
May	2,550	90	554	34,064	.181	.209
June	810	40	122	7,259	.040	.045
July	90	3	13	799	.004	.005
August	205	2	30	1,845	.010	.012
September	2,200	2	153	9,104	.050	.056
October	90	40	55	3,382	.018	.021
November	40	27	37	2,202	.012	.013
December	55	40	51	3,136	.017	.020
The year	16,260	2	556	398,031	.182	2.441

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

NEOSHO RIVER.

Estimated monthly discharge of Neosho River near Iola, Kans.

[Drainage area, 3,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	985	353	444	27,300	0.121	0.140
February	3,570	353	1,224	67,978	.334	.348
March	1,900	552	999	61,426	.272	.314
April	19,250	1,382	6,969	414,684	1.899	2.119
May	1,500	678	1,065	65,484	.290	.334
June	4,250	450	955	56,826	.260	.290
July	353	190	254	15,618	.069	.080
August	190	154	178	10,945	.048	.055
September	142	58	102	6,069	.028	.031
October	58	10	33	2,029	.009	.010
November	70	10	32	1,904	.009	.010
December	94	10	35	2,152	.010	.012
The year	19,250	10	102	732,415	.279	3.743

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

WESTERN GULF DRAINAGE.

During 1901 measurements were continued on the Brazos River at Waco, Tex., and on the Colorado River at Austin, Tex. Results of measurements are here published for the Waco station for the entire period of observation, 1898 to 1901. A hydrographic reconnaissance was made during the month of December, 1901, by Prof. Thomas U. Taylor, of a number of Texas streams, the results of which reconnaissance are published in Water-Supply Paper No. 66, pages 58 to 63. Descriptions of the principal irrigation systems of Texas deriving their water supply from rivers or wells in that State are contained in Water-Supply Paper No. 71, entitled Irrigation Systems of Texas, by Prof. Thomas U. Taylor.

Systematic measurements were kept during 1901 at fifteen gaging stations scattered along the Rio Grande and its tributaries, the first station being at Del Norte, at the head of the San Luis Valley, Colorado, and the last station at Eagle Pass, Tex. The stations along the Lower Rio Grande are maintained by the International (Water) Boundary Commission.

The accompanying diagrams, figs. 50, 51, and 52, furnish an interesting graphic comparison of the discharge of the Rio Grande near El Paso, below Presidio, and near Eagle Pass for 1900 and 1901.

BRAZOS RIVER.

Estimated monthly discharge of Brazos River at Waco, Tex.

[Drainage area, 30,750 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
September 14–30	.....	.....	797	26,874	0.026	0.016
October	1,126	95	347	21,336	.011	.013
November	145	61	85	5,058	.003	.003
December	721	61	144	8,854	.005	.006
1899.						
January	179	76	116	7,133	.004	.005
February	95	61	82	4,554	.003	.003
March	68	26	41	2,521	.001	.001
April	2,968	26	161	9,580	.005	.006
May	5,085	40	1,457	89,587	.047	.054
June	70,682	668	11,203	666,624	.364	.526
July	50,110	1,800	10,945	672,981	.356	.407
August	2,185	118	533	32,773	.017	.019
September	106	50	74	4,403	.002	.002
October	16,750	32	1,127	67,075	.037	.043
November	77,076	365	7,582	451,160	.246	.277
December	11,600	748	2,974	182,864	.097	.112
The year	77,076	26	3,025	2,191,255	.098	1.455
1900.						
January	9,620	860	1,914	117,687	.062	.071
February	830	365	615	34,155	.020	.021
March	3,435	315	791	48,637	.026	.030
April	83,094	668	15,585	927,371	.507	.566
May	46,218	3,365	9,092	559,045	.292	.332
June	35,095	1,322	6,090	362,380	.198	.221
July	10,240	1,220	3,148	193,563	.102	.114
August	5,277	540	2,257	138,777	.073	.084
September	98,832	365	22,213	1,321,767	.722	.802

Estimated monthly discharge of Brazos River at Waco, Tex.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October	35,376	1,082	4,953	304,548	.161	.186
November	12,150	775	1,826	108,655	.059	.066
December	775	415	575	35,355	.019	.022
The year	98,832	315	5,755	4,151,940	.187	2.515
1901.						
January	415	267	344	21,213	.011	.013
February	616	221	392	21,771	.013	.014
March	415	145	232	14,265	.008	.009
April	1,172	179	560	33,322	.020	.018
May	38,017	76	3,670	225,660	.119	.137
June	18,974	221	2,944	175,180	.096	.107
July	267	61	107	6,479	.003	.003
August	1,126	68	431	39,332	.022	.025
September	3,100	61	662	26,501	.014	.016
October	565	95	246	15,126	.008	.009
November	748	76	303	18,030	.010	.011
December	267	76	136	8,362	.004	.005
The year	38,017	61	836	605,241	.026	.367

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 59; rating table on page 178 of same paper.

COLORADO RIVER.

Estimated monthly discharge of Colorado River at Austin, Tex.

[Drainage area, 37,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,704	2,306	2,569	157,962	0.07	0.08
February	2,306	1,908	1,920	106,631	.05	.05
March	1,908	1,190	1,455	89,464	.04	.05
April	3,102	980	1,490	88,661	.04	.04
May	8,674	980	3,148	193,624	.09	.10
June	7,480	290	1,996	118,770	.05	.06
July	40,912	210	4,037	248,225	.11	.13
August	1,908	175	558	34,310	.02	.02
September	21,808	210	4,161	247,597	.11	.13
October	825	290	415	25,517	.01	.01
November	10,664	290	1,690	10,056	.05	.06
December	580	380	484	29,760	.01	.01
The year	40,912	175	1,994	1,350,577	.05	.74

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 64; rating table on page 178 of same paper.

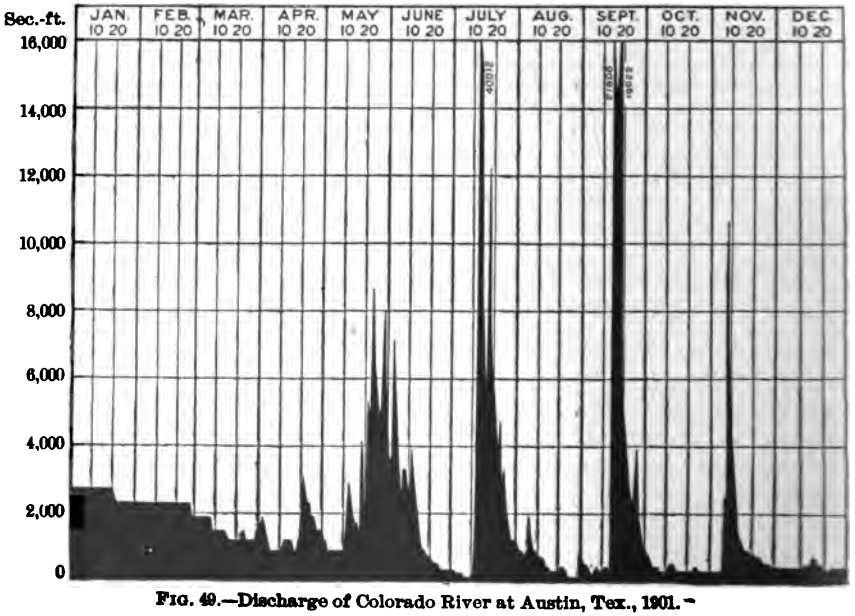


FIG. 49.—Discharge of Colorado River at Austin, Tex., 1901.

RIO GRANDE.

Estimated monthly discharge of Rio Grande near Del Norte, Colo.

[Drainage area, 1,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 800	49,190	[a] 0.57	[a] 0.66
February			[a] 900	49,988	[a] .64	[a] .67
March			[a] 500	30,744	[a] .36	[a] .40
April	1,734	289	710	42,248	.51	.57
May	4,479	1,463	2,570	158,023	1.84	2.12
June	2,754	1,149	1,782	116,036	1.27	1.42
July	1,063	384	594	36,524	.42	.48
August	660	320	464	28,530	.33	.38
September	895	258	446	26,539	.32	.36
October	320	228	262	16,110	.19	.22
November			283	16,840	.20	.22
December			366	22,504	.26	.30
The year			806	593,271	.58	7.80

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 65; rating table on page 173 of same paper.

Estimate monthly discharge of Rio Grande at Cenicero, Colo.

[Drainage area, 7,695 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	594	594	594	36,524	0.0770	0.0890
February	594	414	581	32,267	.0760	.0790
March	774	107	365	22,443	.0470	.0540
April	1,044	107	278	16,542	.0360	.0400
May	2,664	1,224	1,680	103,299	.2180	.2500
June	1,854	236	1,032	61,408	.1340	.1500
July	236	22	82	5,041	.0110	.0130
August	142	31	60	3,689	.0078	.0090
September	58	43	50	2,975	.0063	.0070
October	79	43	54	3,320	.0072	.0083
November	142	43	72	4,284	.0094	.0105
December	414	142	337	20,721	.0440	.0510
The year	2,664	22	432	312,513	.0561	.7608

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 65; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande at Embudo, N. Mex.

[Drainage area, 10,090 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	400	280	341	20,967	0.034	0.039
February	680	350	466	25,880	.046	.048
March	680	350	518	31,851	.051	.059
April	2,020	350	628	37,369	.062	.069
May	6,950	1,700	3,461	212,809	.343	.396
June	4,200	530	1,714	101,990	.170	.190
July	9,700	220	398	24,472	.039	.045
August	1,470	300	451	27,730	.045	.052
September	590	300	359	21,362	.036	.040
October	540	300	331	20,352	.033	.038
November	460	340	359	21,362	.036	.040
December	500	360	423	26,009	.042	.048
The year	9,700	220	787	572,153	.078	1.064

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 66; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande at Rio Grande, N. Mex.

[Drainage area, 14,050 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	610	255	397	24,410	0.028	0.032
February	1,360	420	658	36,543	.047	.049
March	1,275	390	742	45,624	.053	.061
April	4,940	420	1,402	83,425	.100	.112
May	8,400	4,000	5,194	319,367	.370	.430
June	4,740	815	2,199	130,850	.157	.175
July	2,930	280	729	44,824	.052	.060
August	3,450	200	827	50,850	.059	.068
September	2,295	280	580	34,512	.041	.046
October	1,870	320	491	30,190	.035	.040
November	580	380	462	27,491	.033	.037
December	640	260	463	28,468	.033	.038
The year	8,400	200	1,179	856,554	.084	1.148

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 67; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande near San Marcial, N. Mex.

[Drainage area, 23,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	450	30	341	20,967	0.0121	0.0140
February	1,000	290	458	25,468	.0168	.0170
March	480	30	246	15,114	.0088	.0101
April	3,560	0	398	23,683	.0142	.0158
May	5,570	2,880	4,165	256,126	.1484	.1711
June	4,740	60	1,616	96,178	.0574	.0640
July	6,600	0	964	59,286	.0341	.0394
August	5,865	120	1,066	65,534	.0379	.0437
September	6,210	0	632	37,607	.0225	.0251
October	2,320	0	277	17,018	.0099	.0114
November	1,460	160	337	20,053	.0120	.0134
December	460	230	313	19,240	.0111	.0128
The year	6,600	0	901	656,274	.0320	.4388

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 68.

Estimated monthly discharge of Rio Grande near El Paso, Tex.

[Drainage area, 30,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	30	0	5	278	0.0002	0.0002
February	270	0	81	4,503	.0027	.0028
March	410	0	60	3,669	.0016	.0018
April	0	0	0	0	.0000	.0000
May	3,980	110	2,571	158,102	.0857	.0988
June	3,620	20	1,295	77,038	.0432	.0482
July	2,480	0	205	12,576	.0068	.0078
August	3,070	90	986	60,655	.0329	.0379
September	2,650	0	353	21,005	.0118	.0132
October	450	0	87	5,336	.0029	.0033
November	810	40	215	12,813	.0072	.0080
December	130	130	130	7,993	.0043	.0050
The year	3,980	0	499	363,968	.0166	.2270

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 70.

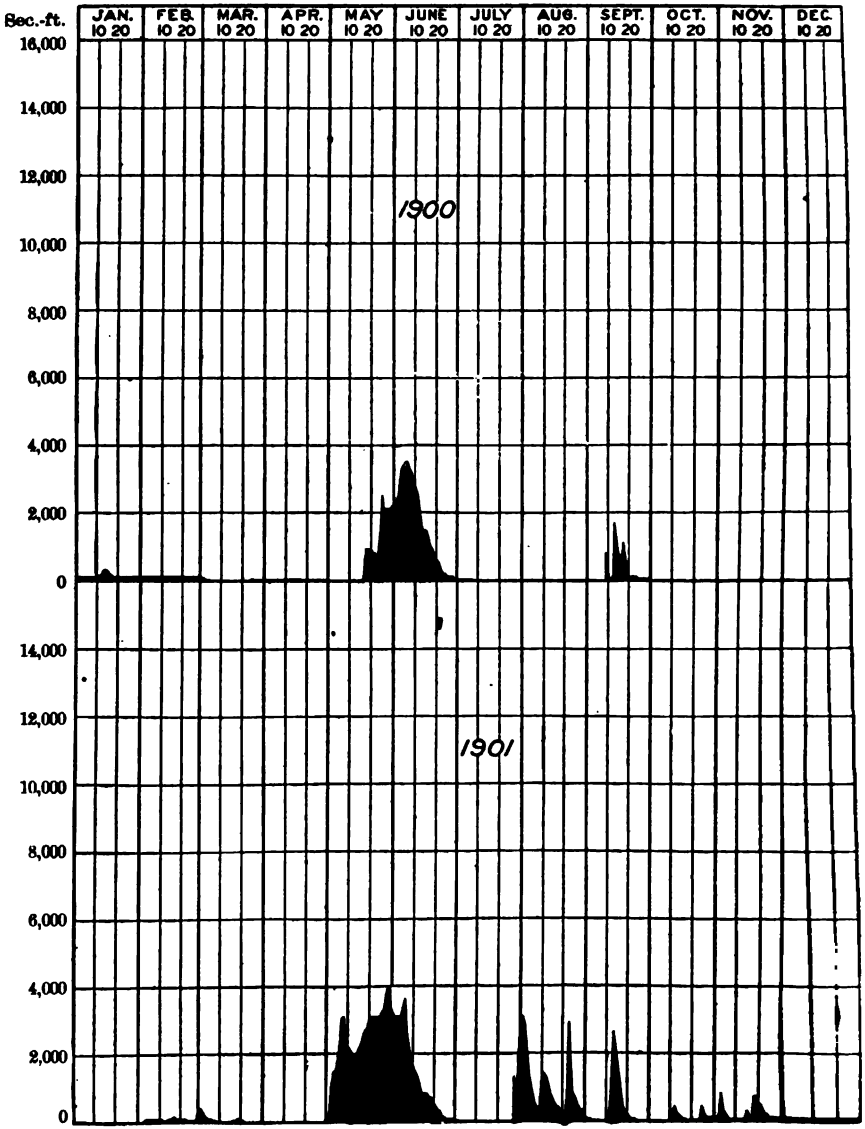


FIG. 50.—Discharge of Rio Grande near El Paso, Tex., 1900-1901.

Estimated monthly discharge of Rio Grande near Fort Hancock, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	2,680	0	1,742	107,127
June	2,710	0	1,015	60,417
July	1,250	0	67	4,126
August	1,770	0	622	38,221
September	1,800	0	241	14,321
October	630	0	94	5,752
November	1,000	30	210	12,476
December	450	40	123	7,736
The year	2,710	0	343	250,176

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 71.

Estimated monthly discharge of Rio Grande above Presidio, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	1,370	0	770	47,326
June	1,620	0	731	43,478
July	830	0	137	8,450
August	1,270	10	462	28,423
September	1,780	30	453	26,936
October	970	0	185	11,365
November	1,020	30	157	9,322
December	130	60	81	4,979
The year	1,780	0	248	180,279

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 72.

Estimated monthly discharge of Rio Grande below Presidio, Tex. (including the flow of Conchos River).

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	200	160	181	11,107
February	780	160	314	17,434
March	440	80	198	12,198
April	80	20	41	2,420
May	1,800	20	720	44,291
June	1,530	50	763	45,422
July	3,470	20	999	61,408
August	3,120	820	1,793	110,241
September	5,410	640	2,206	131,266
October	5,690	330	1,223	75,213
November	1,500	330	593	35,266
December	450	260	300	18,466
The year	5,690	20	778	564,732

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 74.

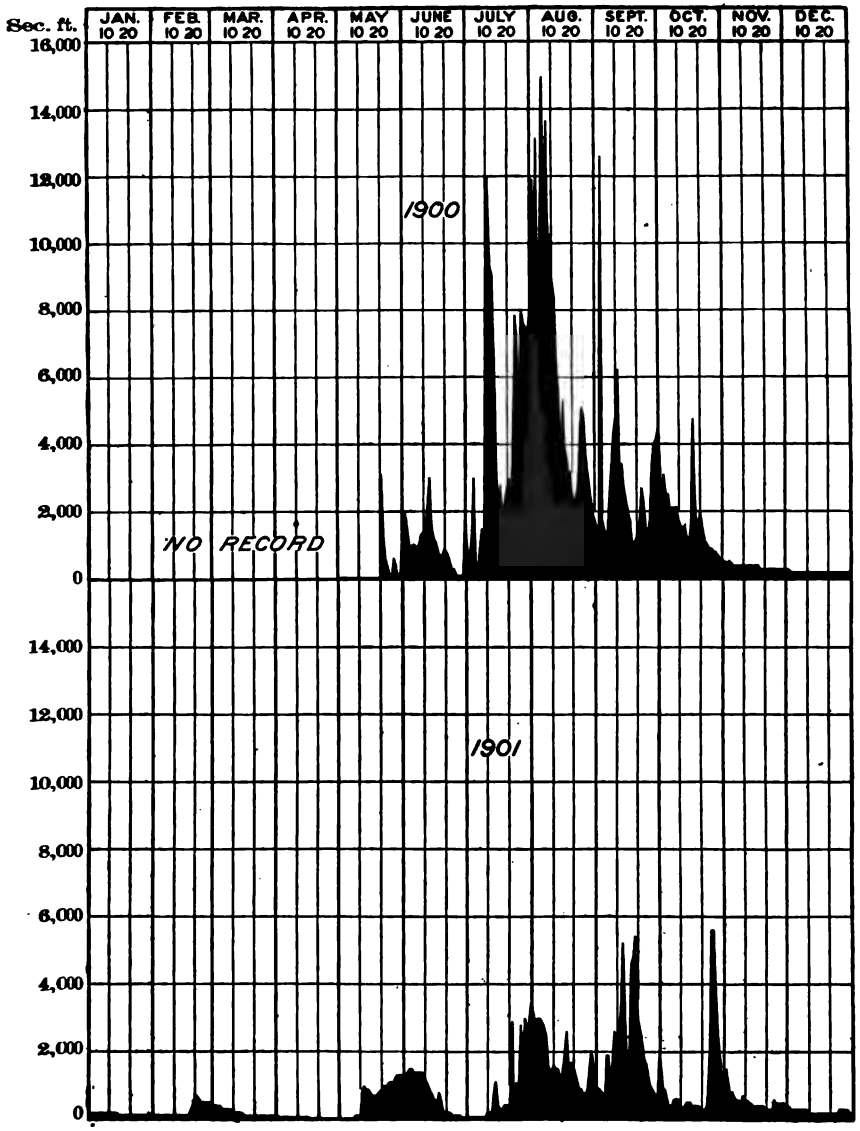


FIG. 51.—Discharge of Rio Grande below Presidio, Tex., 1900-1901.

Estimated monthly discharge of Rio Grande near Langtry, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	620	570	600	36,893
February	920	520	599	33,263
March	890	450	627	38,559
April	920	370	425	25,309
May	3,500	450	1,163	71,524
June	2,350	600	1,465	87,174
July	3,510	500	1,314	80,767
August	3,920	820	2,306	141,818
September	14,700	1,210	3,418	203,385
October	5,120	1,100	1,900	116,846
November	2,610	930	1,367	81,322
December	1,120	800	875	53,773
The year	14,700	370	1,338	970,632

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 75.

Estimated monthly discharge of Pecos River near Moorhead, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	570	440	508	31,240
February	610	500	563	31,260
March	530	360	443	27,213
April	380	280	306	18,208
May	670	280	348	21,421
June	440	190	321	19,121
July	1,270	160	341	20,945
August	1,220	200	688	42,307
September	9,200	350	1,295	77,078
October	850	420	561	34,512
November	2,690	490	1,435	85,369
December	1,200	500	790	48,575
The year	9,200	160	633	457,249

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 78.

Estimated monthly discharge of Devils River at Devilsriver, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	840	810	831	51,074
February	840	750	801	44,489
March	830	720	748	46,017
April	750	670	685	40,760
May	670	660	665	40,919
June	670	580	604	35,921
July	750	570	583	35,841
August	670	500	556	34,215
September	700	510	529	31,478
October	520	520	520	31,974
November	520	510	515	30,664
December	510	480	489	30,069
The year	840	480	627	453,421

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 79.

Estimated monthly discharge of Rio Grande near Devilsriver, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	2,330	2,160	2,277	140,033
February	2,870	2,120	2,260	125,497
March	2,570	1,920	2,180	133,964
April	2,070	1,620	1,719	102,288
May	3,610	1,750	2,189	134,588
June	3,770	1,950	2,669	158,816
July	5,250	1,830	2,452	150,783
August	6,000	2,650	3,907	240,218
September	34,280	2,490	5,863	348,873
October	11,500	2,630	3,938	242,122
November	5,180	2,969	3,897	231,888
December	3,350	2,360	2,748	168,992
The year	34,280	1,620	3,008	2,178,062

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 80.

Estimated monthly discharge of Rio Grande near Eagle Pass, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	3,420	2,750	3,054	187,795
February	2,740	2,510	2,616	145,369
March	2,610	2,020	2,277	140,033
April	2,300	1,780	1,934	115,081
May	4,410	2,200	3,108	191,107
June	5,430	1,770	3,571	212,509
July	3,800	1,600	2,376	146,122
August	5,240	2,800	4,249	261,243
September	21,460	2,840	5,593	332,807
October	7,600	2,380	3,444	211,775
November	4,400	2,680	3,644	216,833
December	2,670	2,010	2,245	138,089
The year	21,460	1,600	3,176	2,298,763

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 81.

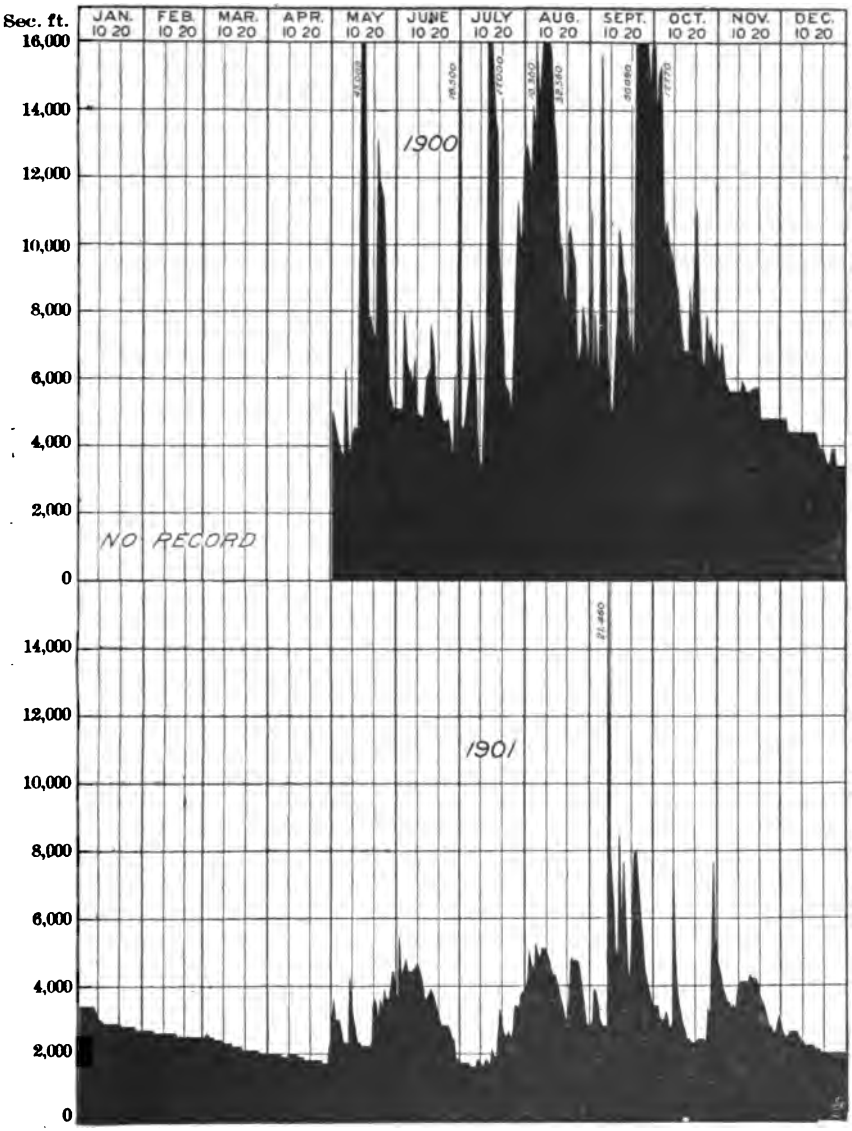


FIG. 52.—Discharge of Rio Grande near Eagle Pass, Tex., 1900-1901.

COLORADO RIVER DRAINAGE.

Considerable hydrographic work was carried on in the basin of Colorado River during the field season of 1901. Systematic stream measurements were made at all the stations maintained during the preceding year, with the exception of the station on Grand River at Grand Junction, Colo., which was abandoned. New stations were established during the year at Craig, Colo., on Yampa River; at

Meeker, Colo., on White River; at Whitewater, Colo., on Gunnison River; near Livingston, Ariz., on Tonto Creek, and on Salt River above the mouth of Tonto Creek. The latter two stations were established in connection with an investigation into the water supply for the proposed reservoir on Salt River. Similar investigations were conducted on Verde River during 1901. A detailed report of these investigations containing plans and estimates of the proposed dams has been published in Water-Supply Paper No. 73, entitled "Water Storage on Salt River, Arizona," by Arthur P. Davis, under whose direction the work was carried on.

Regular measurements were resumed at Greenriver station on Green River, in Wyoming, which station had been discontinued in March of the preceding year. The stations established on Duchesne River and tributaries during the fall of 1899 by C. C. Babb, in connection with his surveys for a water supply for the Uinta Indian Reservation, were maintained during 1901. Results of this investigation are given elsewhere in this report.

Two more investigations were carried on in the Colorado River Basin during the field season of 1901, one being a project for diverting water from Gunnison River into the valley of the Uncompahgre River for irrigating purposes, and the other consisting of a reconnaissance of Lower Colorado River for the purpose of discovering dam and reservoir sites.

GREEN RIVER.

Estimated monthly discharge of Green River at Greenriver, Wyo.

[Drainage area, 7,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	2,880	500	1,325	78,843	0.18	0.20
May	12,410	1,782	6,753	415,226	.91	1.05
June	10,214	3,405	5,416	322,274	.73	.81
July	4,202	1,845	2,751	169,152	.37	.43
August	2,455	905	1,411	86,759	.19	.22
September	905	500	632	37,607	.08	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 82; rating table on page 173 of same paper.

UINTA RIVER.

Estimated monthly discharge of Uinta River near Whiterocks, Utah.

[Drainage area, 218 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a] 140	8,608	0.64	0.74
February	[a] 140	7,775	.64	.67
March	[a] 150	9,223	.69	.80
April	[a] 179	10,651	.82	.92
May	[a] 684	42,058	3.14	3.62
June	[a] 355	21,124	1.63	1.82
July	[a] 251	15,433	1.15	1.33
August	[a] 242	14,880	1.11	1.28
September	[a] 193	11,484	.89	.99
October	[a] 163	10,022	.75	.86
November	[a] 142	8,450	.65	.73
December	[a] 147	9,039	.67	.77
The year	[a] 232	168,747	1.07	14.53

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 84; rating table on page 173 of same paper.

Estimated monthly discharge of Whiterocks River near Whiterocks, Utah.

[Drainage area, 114 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a] 50	3,074	0.44	0.51
February	[a] 50	2,777	.44	.46
March	[a] 50	3,074	.44	.51
April	[a] 74	4,403	4.65	.73
May	[a] 507	31,174	.45	5.13
June	[a] 179	10,651	1.57	1.75
July	[a] 101	6,210	.89	1.03
August	[a] 128	7,870	1.12	1.29
September	[a] 95	5,653	.83	.93
October	[a] 75	4,612	.66	.76
November	[a] 63	3,749	.55	.61
December	[a] 61	3,751	.54	.62
The year	[a] 119	86,998	1.05	14.33

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 85; rating table on page 173 of same paper.

Estimated monthly discharge of Uinta River at Fort Duchesne, Utah.

[Drainage area, 672 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 135	8,301	0.20	0.23
February			[a] 135	7,498	.20	.21
March	295	77	132	8,116	.20	.23
April	184	87	117	6,962	.17	.19
May	4,520	218	1,188	73,047	1.77	2.04
June	485	184	261	15,531	.39	.44
July	201	97	140	8,608	.21	.24
August	2,120	87	168	10,330	.25	.29
September	184	97	121	7,200	.18	.20
October	184	97	116	7,133	.17	.20
November	137	109	117	6,962	.17	.19
December			[a] 130	7,993	.19	.22
The year			[a] 230	167,681	.34	4.68

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 86; rating table on page 174 of same paper.

Estimated monthly discharge of Uinta River at Ouray School, Utah.

[Drainage area, 967 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 120	7,379	0.12	0.14
February			[a] 120	6,664	.12	.12
March		92	116	7,133	.12	.14
April	151	92	116	6,902	.12	.13
May	3,450	215	1,137	69,911	1.18	1.36
June	598	181	309	18,387	.32	.36
July	192	58	114	7,010	.12	.14
August	953	52	164	10,084	.17	.20
September	192	100	121	7,200	.13	.15
October	181	108	123	7,563	.13	.15
November	142	116	126	7,498	.13	.15
December			[a] 115	7,071	.12	.14
The year			[a] 223	162,802	.23	3.1[illegible]

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 87; rating table on page 174 of same paper.

A. DUCHESNE RIVER 1 MILE ABOVE PRICE ROAD BRIDGE, UTAH.

B. DUCHESNE RIVER IMMEDIATELY ABOVE MOUTH OF UINTA RIVER, UTAH.

Estimated monthly discharge of Lake Creek, Utah, near mouth.

[Drainage area, 475 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a] 95	5,841	0.20	0.23
February	[a] 95	5,276	.20	.21
March	[a] 100	6,149	.21	.24
April	[a] 132	7,855	.28	.31
May	[a] 1,272	78,212	2.68	3.09
June	[a] 556	33,084	1.17	1.31
July	[a] 250	15,372	.53	.61
August	[a] 255	15,679	.54	.62
September	[a] 144	8,569	.30	.33
October	[a] 132	8,116	.28	.32
November	[a] 112	6,664	.24	.27
December	[a] 110	6,764	.23	.27
The year	[a] 271	197,581	.57	7.81

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 88 rating; table on page 174 of same paper.

Estimated monthly discharge of Duchesne River at Price road bridge, Utah.

[Drainage area, 2,746 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 280	17,217	0.10	0.12
February			[a] 280	15,550	.10	.10
March		278	289	17,770	.11	.13
April	1,193	247	498	29,633	.18	.20
May	6,675	1,193	3,169	194,854	1.15	1.33
June	2,862	870	1,485	88,364	.54	.60
July	910	408	597	36,708	.22	.25
August	950	313	453	27,854	.16	.18
September	408	262	307	18,268	.11	.12
October	439	278	322	19,799	.12	.14
November	355	278	316	18,803	.12	.13
December			[a] 300	18,446	.11	.13
The year			691	503,266	.25	3.43

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 89; rating table on page 174 of same paper.

ASHLEY CREEK.

This stream drains an area in northeastern Utah directly east of the Uinta River drainage. It flows southeasterly, entering Green River about 25 miles below the place where the latter stream crosses the State line between Colorado and Utah. About 7½ miles above the town of Vernal the creek leaves its mountainous area and enters what is known as Vernal Valley. This valley is approximately 20 miles long and 3 miles wide, its boundaries being sharply defined by the foothills. A large portion of the valley has been taken up by

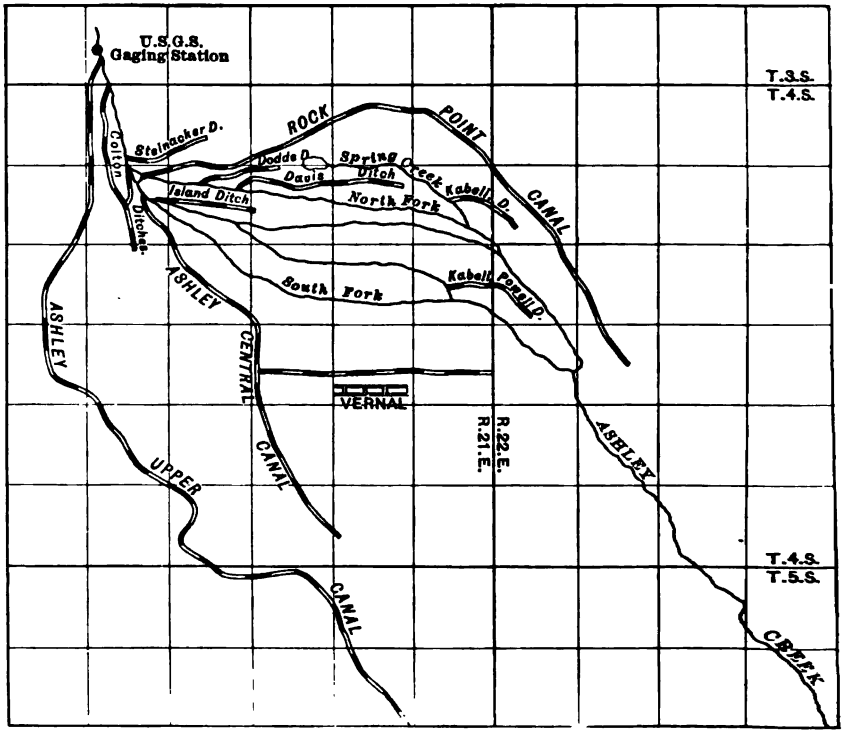


FIG. 53.—Canal system of Vernal Valley, Utah.

white settlers, and a considerable acreage is now under cultivation through irrigation.

There are three principal canals in use. Upper Ashley canal, on the west, built in 1882, covers 11,200 acres. The stock of the company is divided into 1,120 shares of a face value of $25 per share, and each share is for water to irrigate 10 acres. During the census year 1900 the area irrigated under this canal was 6,500 acres. Central Ashley canal, on the west side, built in 1880, covers 8,400 acres, 7,000 acres of which were irrigated in 1900. Each share is for sufficient water for 20 acres and is worth $50, or $2.50 per acre. Rock Point canal, on the east side, built in 1880, covers about 2,000 acres, 1,400

acres of which were irrigated in 1900. The stock of the company is divided into 250 shares of a face value of $10 per share, and each share is for water sufficient for 7½ acres. There are a number of smaller canals lower down, the principal one being known as Island ditch, which controls 900 acres, 400 acres of which were irrigated in the census year 1900. The stock of the various canal companies is private property. A farmer, if entitled to a certain amount of water, is not supposed to rent or otherwise dispose of any portion of it, but it is often the case that he does.

By a decree of the district court dated November 17, 1897, the waters of Ashley Creek are divided as follows: Upper Irrigation Canal Company (Upper Ashley canal), $\frac{80}{81}$ of one-third of the discharge; Ashley Central Irrigation Canal Company, $\frac{86}{87}$ of one-third of the discharge; Rock Point and other canals (Union, Turner & Dodds, Island, Steinacker, and Colton), $\frac{75}{77}$ of one-third of the discharge; and Green River interveners the remainder. In accordance with this bill the water commissioner ordered all canal companies to install weirs so constructed as to bring the water to a quiet state 60 feet above the weirs. A weir 30 feet wide was placed in the river above the head of all canals, and weirs of the following dimensions were ordered placed in the canals, the sum of the width of the weirs being approximately the width of the river weir:

Weirs on Ashley Creek canals.

	Ft.	In.
Upper Ashley canal	9	10.4
Central Ashley canal, including Green River interveners (5.75 inches) and deducting Colton canal (3.70 inches)	10	.47
Union canal		7.11
Turner & Dodds ditch		11.52
Island ditch		17.41
Steinacker ditch		3.52
Rock Point canal	5	8.79
Colton ditch (decree of court $\frac{164}{2252}$, deed from Central Ashley canal $\frac{3}{97}$)		12.21

The two Ashley canals and the Rock Point canal are the only ones maintaining weirs. They are of the rectangular type, so constructed that each has two end contractions. No attempt is made to measure the quantity of water. When the creek is at its lowest stages, and it becomes necessary to divide the water among the canals, the flow into them is so regulated that exactly the same height of water is permitted to pass over each weir, the regulation stake, which is level with the crest of the weir, being placed a short distance above. As the lengths of the weirs correspond with the court decrees the amount of water is supposed to be in the required proportion. On account of the end contractions of the weirs of the two Ashley canals and the Rock Point canal, those ditches do not receive the same proportion of water for varying heights, as the reduction of length for end contractions is a function of the height of the water.

During the flood stages of the creek more water passes down it than the canals can carry, and therefore no attempt is then made to divide the water. It is only when lower stages of the creek are reached that the water is divided. No head gates are maintained in the canals, the flow being regulated by placing or removing rocks in the rough dam—an unsatisfactory method, of course.

The principal canals of the valley were measured twice during 1900, once in May, when the creek was in flood and a considerable amount of water was passing all canals and wasting into the stream below. The measurements, therefore, show approximately the maximum capacity of the various ditches. A second series of measurements was made in August, when the creek was at a low stage and after the water had been divided. The following table contains the results of the measurements made:

Discharge measurements in Vernal Valley, Utah.

Date.	Stream.	Locality.	Discharge.
1900.			*Sec. feet.*
May 28	Ashley Creek	Gaging station	776.0
May 29	Upper Ashley canal	Measuring weir	181.0
Do	Central Ashley canal	do	138.0
Do	Rock Point canal	Near head	35.0
Do	Steinacker canal	do	1[illegible]
Aug. 21	Ashley Creek	Gaging station	40.0
Do	Upper Ashley canal	Measuring weir	12.0
Do	Central Ashley canal	do	10.0
Do	Rock Point canal	Near measuring weir	6.[illegible]

The population of Vernal Valley is 6,000. There are 38,000 acres of land on the valley tax rolls, only 25,000 acres of which are under ditch, according to the Twelfth Census. The following data are taken from the same authority:

The amount of land irrigated in 1900 was 17,471 acres. The average cost of a water right in the valley is $3 per acre, and the annual cost for maintenance is 15 cents per acre. An acre of land without water is valued at $1.25, but as soon as it is placed under ditch and is assured a good water supply the value increases to $30. The length of the irrigation season is six months—from April 1 to October 1.

The records of the flow of Ashley Creek at the gaging station in the canyon for the season of 1900 showed a total discharge of 56,225 acre-feet. The combined maximum capacity of the canals of the valley is 350 second-feet. May was the only month in 1900 in which there was more water than the canals could carry, as the average discharge for that month was 478 second-feet, or an excess of 128 second-feet. The latter amount represents an excess of 7,870 acre-feet. Subtracting this amount from the total discharge of the river for the period

will leave 48,355 acre-feet, the amount of water which approximately was spread over the area irrigated, 17,471 acres, during 1900. This is an average depth of 2.8 feet.

The discharge of 48,355 acre-feet for the six months represents a mean flow of 133 second-feet, or, expressed in other terms, the duty of water was 1 second-foot to 131 acres. The autumn is the season of low-water stages for the streams in this vicinity. The principal crops of the valley are alfalfa and oats. In the lower portion of the valley seepage water is now appearing in the river channels and is being used for irrigation purposes, thus increasing the duty of water in that section.

There is a voluntary observer of the Weather Bureau at Vernal, who has kept a continuous record for five years, the mean annual precipitation for that period being 9.38 inches. The precipitation in 1899 was 8.41 inches, and the mean temperature 46 degrees. There is no well-defined rainy season, but the principal rainfalls occur in June or July. The snowfall is generally light, the air usually dry, and strong winds are infrequent. The soil is a sandy loam. The mineral resources are said to be excellent in the surrounding mountains, deposits of gold, silver, and copper being worked to some extent. Coal is also found near by, and some deposits of uintaite of the asphaltum series. Transportation facilities are poor. The railroad is reached at Price, 140 miles distant, by way of Fort Duchesne.

East of Ashley Creek are two peculiar streams of the "disappearing" type, known as Little Brush Creek and Big Brush Creek. The main Brush Creek enters Green River 3 miles above the mouth of Ashley Creek. The peculiarity of these two forks is that their waters disappear and then reappear at various points along their courses. At one place Big Brush Creek enters a long, precipitous tunnel which has been only partly explored, and in which icicles and banks of ice are said to exist the year round.

As a result of a number of reports upon certain curious conditions said to exist in the basin of the Dry Fork, a tributary of Ashley Creek, a reconnaissance of the basin was made in August, 1901, by Mr. C. T. Prall, and from his report the following facts are taken:

The Dry Fork has its source in a lake in the Uinta Mountains about 35 miles northwest of Vernal. Its length is about 28 miles, 23 miles of which is in canyon varying in width from 500 feet to a half mile, and 5 miles is through a valley 1½ miles wide. The general course of the stream is southeast and the fall is heavy, at least 150 feet to the mile. It enters Ashley Creek about 8 miles above the town of Vernal. About midway the stream's length, or 10 miles northwest of Dry Fork post-office, a gaging was made on August 20, 1901, which gave a discharge of 96 second-feet. About 1,200 feet below that point occurs a pool or sink lying in a circular basin, whose banks, except on the

upstream side, are from 75 to 100 feet high. The stream enters this pool through several inlets. It is apparently bottomless, and the water in the larger end has a slow, circular motion, but whether this is caused by the incoming streams or by suction from below could not be determined. The only visible outlet from the pool is a narrow, rocky channel which has been widened, by blasting, in an effort to increase its flow. It was carrying about 10 second-feet when measured, but this water sank in a mile, or thereabouts.

Three miles below the pool the North Branch enters. One mile above its mouth 8 second-feet were flowing at the time of measurement, but the water vanished almost immediately upon reaching the main channel. Seven miles below the pool are located several springs, the upper and largest being a hole 25 feet in diameter. This spring was perfectly dry, but the lower ones were sending out 33 second-feet. A resident in the Dry Fork settlement since 1879 stated that only once before, to his knowledge, had these springs furnished water after the subsidence of the usual spring freshet. It was also stated that owing to recent rains the stream above the pool was higher than usual. Two miles below the springs, at the canyon's mouth, are located two ditches, but they had carried no water for several weeks. The stream bed was dry from the heads of the ditches to its mouth, a distance of 5 miles.

About 250 feet above the mouth of the Dry Fork a gaging of Ashley Creek showed 132 second-feet. About 400 feet below the mouth of the Dry Fork the discharge was 128 second-feet. A closer check than this would probably be impossible in view of the rather rough character of the creek's bed. One mile below the Dry Fork, at the regular gaging station, a discharge of 154 second-feet was found. The increase shown here is due to a ditch diverting water from the east side of Ashley Creek a short distance above the mouth of the Dry Fork and returning the water to the creek again above the gaging station. Two small ditches carrying a total of 3 second-feet are taken out of Ashley Creek between the Dry Fork and the gaging station.

The Dry Fork Valley comprises about 1,000 acres of arable land, all of which is under cultivation. Good crops are raised through use of spring flood waters, but much better results could be obtained by a more certain supply. However, a very small portion of the flow of the stream would suffice, leaving a large amount which could be used to excellent advantage in Ashley Valley. The visible supply in the two branches of the Dry Fork on August 21 was 104 second-feet, of which amount 33 second-feet found its way into the ditches. A flume 7 miles in length would carry the water below all known sinks, where it could be turned back into the stream and be subject to only the usual losses from seepage, etc. Even if 30 per cent were lost in trans-

mission, a stream capable of much good would still be available. A V-shaped flume was partly constructed some years ago, starting above the pool. It has fallen into disuse, but it is understood that plans are being made to rebuild it.

March 15, 1900, a gaging station, described in Water-Supply Paper No. 50, page 368, was established by C. T. Prall in the canyon of Ashley Creek, 7½ miles above the town of Vernal, and a short distance above the head of the upper canal. The gage is a vertical rod, painted white, fastened to the west side of the single pier of the wagon bridge. The bench mark is a 20-penny nail driven in the pier opposite the 4-foot mark. Results of measurements for 1901 are given in the following table:

Estimated monthly discharge of Ashley Creek near Vernal, Utah.

[Drainage area, 250 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	36	36	36	2,214	0.14	0.16
February	43	36	36	1,999	.14	.15
March	55	34	37	2,275	.15	.17
April	864	34	122	7,260	.49	.55
May	1,136	354	683	41,996	2.73	3.15
June	460	141	232	13,805	.93	1.04
July	141	72	100	6,149	.40	.46
August	932	72	149	9,162	.60	.69
September	131	72	96	5,712	.38	.42
October	72	55	62	3,812	.25	.29
November	63	48	58	3,451	.23	.26
December	55	48	52	3,197	.21	.24
The year	1,136	34	139	101,032	.55	7.58

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 83; rating table on page 173 of same paper.

GRAND RIVER.

Estimated monthly discharge of Grand River at Glenwood Springs, Colo.

[Drainage area, 5,838 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	810	550	688	42,180	0.12	0.14
February	970	630	746	41,430	.13	.13
March	970	727	837	51,465	.14	.16
April	7,100	727	1,888	112,343	.32	.36
May	22,895	6,420	13,797	848,529	2.36	2.72
June	15,660	9,620	12,174	724,404	2.09	2.33
July	10,765	2,090	4,833	297,170	.83	.96
August	3,630	1,350	1,907	117,072	.33	.38
September	1,460	840	1,045	62,182	.18	.20
October	970	870	917	56,445	.16	.18
November	935	810	879	52,364	.15	.17
December	935	630	788	48,452	.14	.16
The year	22,895	550	3,375	2,454,039	.58	7.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 92; rating table on page 174 of same paper.

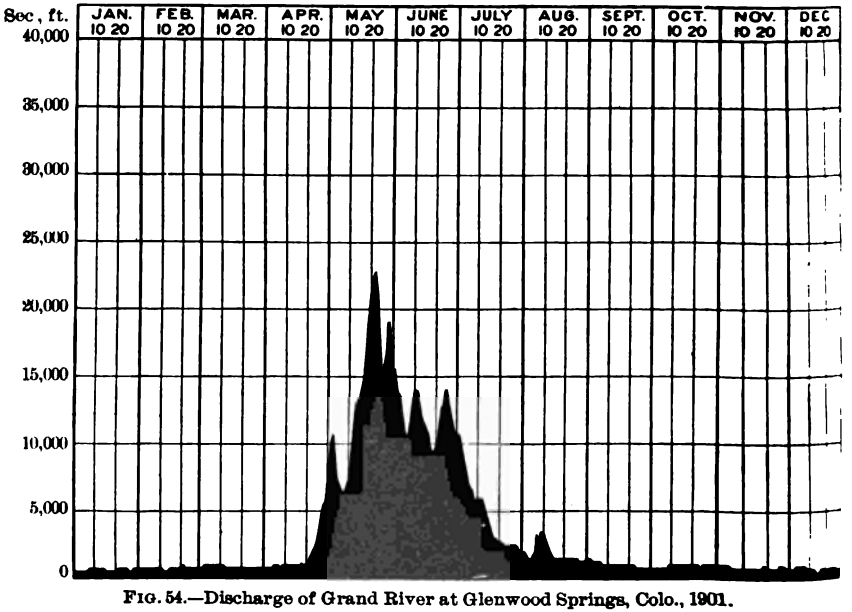


FIG. 54.—Discharge of Grand River at Glenwood Springs, Colo., 1901.

GUNNISON RIVER.

Estimated monthly discharge of Gunnison River at Iola, Colo.

[Drainage area, 2,298 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	2,442	426	910	54,148	0.39	0.44
May	7,402	2,137	3,756	230,949	1.55	1.79
June	3,686	2,289	2,892	172,086	1.24	1.38
July	2,289	663	1,151	70,773	.49	.56
August	1,118	496	676	41,750	.29	.33
September	663	300	399	23,742	.16	.18
October	361	300	322	19,799	.12	.14
November	361	300	310	18,446	.12	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 93; rating table on page 174 of same paper.

DOLORES RIVER.

Estimated monthly discharge of Dolores River at Dolores, Colo.

[Drainage area, 524 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March	555	82	178	10,945	0.34	0.39
April	2,386	82	878	52,245	1.68	1.87
May	3,086	1,371	2,085	128,201	3.98	4.59
June	1,686	810	1,206	71,524	2.30	2.46
July	627	141	266	16,355	.51	.59
August	343	100	174	10,698	.33	.38
September	220	19	42	2,499	.08	.09
October	37	19	26	1,599	.05	.06

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 95; rating table on page 174 of same paper.

LOS PINOS RIVER.

Estimated monthly discharge of Los Pinos River at Ignacio, Colo.

[Drainage area, 450 square miles.]

Month.	Discharge in second-feet			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,166	109	452	26,896	1.00	1.12
May	1,569	735	1,026	63,086	2.28	2.63
June	887	645	763	45,402	1.70	1.90
July	555	83	226	13,896	.50	.58
August	825	95	202	12,420	.45	.52
September 1-26			[a]186	9,592	.47	.40

[a] Partial month.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 96; rating table on page 174 of same paper.

FLORIDA RIVER.

Estimated monthly discharge of Florida River near Durango, Colo.

[Drainage area, 136 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	339	21	110	6,545	0.81	0.90
May	625	248	377	23,181	2.77	3.20
June	326	41	172	10,235	1.27	1.42

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 96; rating table on page 174 of same paper.

VERDE RIVER.

Estimated monthly discharge of Verde River near McDowell, Ariz.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,500	259	351	21,575	0.059	0.067
February	6,613	394	1,859	103,249	.310	.323
March	2,863	211	895	55,018	.149	.172
April	221	155	185	10,988	.031	.034
May	185	125	140	8,606	.023	.027
June	164	59	105	6,222	.017	.019
July	1,680	29	210	12,916	.035	.040
August	3,000	163	627	38,561	.105	.121
September	172	45	93	5,514	.015	.017
October	730	82	134	8,210	.022	.025
November	336	187	245	14,571	.041	.046
December	288	247	268	16,485	.045	.052
The year	6,613	29	426	302,615	.071	.943

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 103.

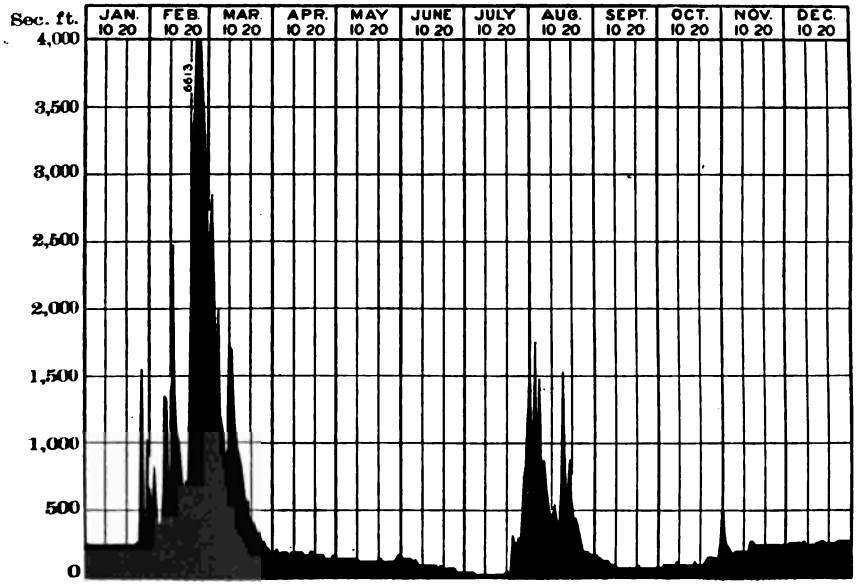


FIG. 55.—Discharge of Verde River near McDowell, Ariz., 1901.

SALT RIVER.

Estimated monthly discharge of Salt River at reservoir site, Arizona.

[Drainage area, 5,756 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			454	27,945	0.08	0.09
February	4,172	928	2,414	134,047	.42	.44
March	3,468	740	1,423	87,472	.25	.29
April	1,562	740	1,050	62,442	.18	.20
May	1,267	462	735	45,203	.13	.15
June	508	147	288	17,262	.05	.06
July	3,556	71	346	21,296	.06	.07
August	2,221	207	529	32,504	.09	.10
September	670	123	309	17,907	.05	.06
October	215	117	152	9,334	.03	.03
November	215	183	189	10,629	.03	.03
December	195	180	190	11,663	.03	.03
The year			672	477,704	.11	1.55

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 99.

Estimated monthly discharge of Tonto Creek near Livingston, Ariz.

[Drainage area, 1,080 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	40	16	27	1,622	0.026	0.029
May	43	6	14	865	.014	.016
June	9	0	5	201	.005	.006
July	959	2	37	2,255	.036	.04[illegible]
August	279	0	27	1,686	.026	.03[illegible]
September	8	2	3	175	.003	.0[illegible]
October	2	2	2	123	.002	.0[illegible]
November	3	2	3	170	.003	.0[illegible]
December	2	2	2	123	.002	.0[illegible]

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 101.

Estimated monthly discharge of Salt River near McDowell, Ariz.

[Drainage area, 6,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,172	235	582	35,788	0.09	0.10
February	5,100	1,412	2,422	134,517	.39	.41
March	3,157	827	1,634	100,494	.26	.30
April 1–19 [a]			1,005	37,895	.16	.11
June	590	128	284	16,972	.05	.06
July			[b] 152	[b] 9,350	[b] .02	[b] .02
August	1,130	205	[b] 369	[b] 22,711	[b] .06	[b] .07
September	710	121	192	11,420	.03	.03
October	191	118	143	8,816	.02	.02
November	209	155	189	11,218	.03	.03
December	189	157	182	11,185	.03	.03

[a] No observations made from April 20 to June 1. [b] Estimated.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 102.

GILA RIVER.

Estimated monthly discharge of Gila River at San Carlos, Ariz.

[Drainage area, 13,455 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,330	110	199	12,236	0.0148	0.0171
February	2,080	450	1,079	59,925	.0802	.0835
March	1,070	155	446	27,423	.0332	.0383
April	155	5	53	3,154	.0039	.0044
May	8	5	5	307	.0004	.0005
June	5	0	3	178	.0002	.0002
July	4,200	0	368	22,627	.0273	.0315
August	3,050	10	536	32,957	.0398	.0459
September	8,500	2	250	14,876	.0186	.0208
October	1,000	2	91	5,595	.0068	.0078
November	680	125	232	13,805	.0172	.0192
December	125	100	109	6,702	.0081	.0093
The year	8,500	0	281	199,785	.0209	.2785

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 99.

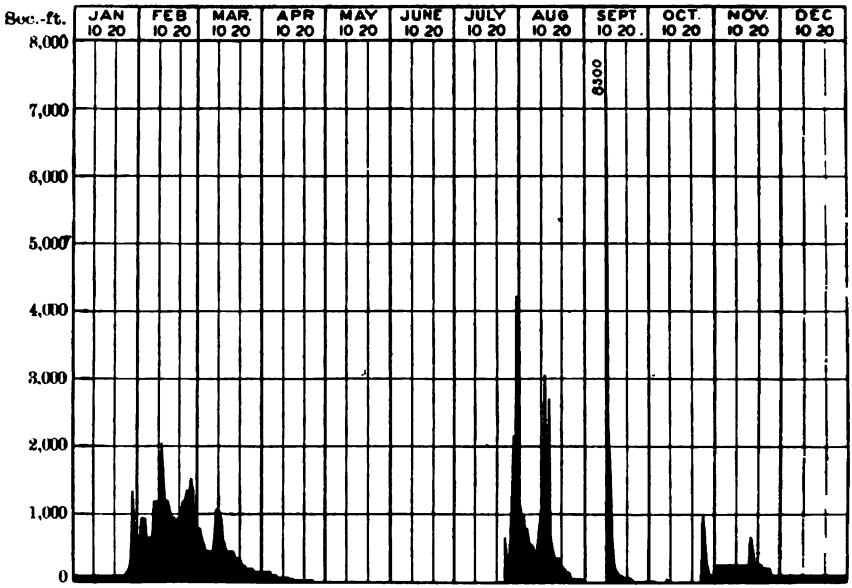


FIG. 56.—Discharge of Gila River at San Carlos, Ariz., 1901.

INTERIOR BASIN DRAINAGE.

Under this head is comprised the large extent of arid country which includes nearly the whole of Nevada, the northern and western parts of Utah, and small portions of California and Idaho. Having no outlet to the sea, the entire drainage of this vast basin is lost mainly through evaporation from the numerous lakes and sinks in which the waters of the rivers collect. During 1901 measurements were made of the streams draining into all of the principal lakes of the interior basin, with the exception of Walker River draining into Walker Lake.

In the Great Salt Lake drainage the following rivers were measured: Bear River and tributaries, Weber River, and Ogden River. In Utah Lake drainage, American Fork, Provo River, and Spanish Fork. In Sevier Lake drainage, Sevier River and its tributaries, the San Pitch and the Salina.

Humboldt River, draining into Humboldt sink, was measured at four places, viz, near Elko, near Golconda, and near Oreana, on the main stream, and at Mason's ranch, on the South Fork.

Truckee River, flowing into Lake Tahoe and thence into Pyramid Lake, is measured at Tahoe at the outlet of the lake, at the California-Nevada State line, and at Vista, Nev. Steamboat Creek, a tributary of the Truckee, is gaged at Steamboat Springs.

Carson River, the waters of which disappear in Carson sink, is measured at Empire, Nev. Its main tributaries, the East and West

forks, are gaged near Gardnerville, Nev., and at Woodfords, Cal., respectively.

A number of reservoir sites were surveyed in the Truckee River Basin during the season of 1901. Descriptions of these sites, together with estimates of cost of construction and of the amount of land to be irrigated, are published in Water-Supply Paper No. 68, entitled Water Storage in the Truckee River Basin, by L. H. Taylor, under whose direction the surveys were made.

The principal tributary of Honey Lake is Susan River. Measurements have been made on this stream during 1901 near Susanville, Cal., and on Willow Creek, a tributary, near Standish, Cal.

HUMBOLDT RIVER.

Estimated monthly discharge of Humboldt River, near Elko, Nev.

[Drainage area, 2,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	70	63	65	3,997	0.023	0.027
February	2,339	49	671	37,265	.236	.246
March	1,121	284	480	29,514	.169	.195
April	374	253	295	17,553	.104	.116
May	822	319	511	31,420	.180	.208
June	594	32	353	21,005	.124	.138
July	123	14	50	3,074	.018	.021
August	43	.5	12	738	.004	.005
September	18	.5	6	357	.002	.002
October	22	4	8	492	.003	.003
November	10	7	9	536	.003	.003
December	10	10	10	615	.004	.005
The year	2,339	0.5	206	146,566	.072	.969

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 104; rating table on page 174 of same paper.

Estimated monthly discharge of South Fork of Humboldt River at Mason's Ranch, Nev.

[Drainage area, 1,150 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	35	24	33	2,029	0.029	0.033
February	1,478	35	408	22,659	.355	.370
March	382	122	173	10,637	.150	.173
April	263	122	180	10,711	.157	.175
May	619	276	457	28,100	.397	.458
June	589	182	379	22,552	.330	.368
July	182	41	81	4,980	.070	.081
August	41	4	21	1,291	.018	.021
September	19	4	8	476	.007	.008
October	47	19	37	2,275	.032	.037
November	67	47	55	3,273	.048	.054
December	67	35	51	3,136	.044	.051
The year	1,478	4	157	112,119	.136	1.829

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 105; rating table on page 174 of same paper.

Estimated monthly discharge of Humboldt River near Golconda, Nev.

[Drainage area, 10,780 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	108	40	65	3,997	0.0060	0.0069
February	1,290	59	323	17,939	.0300	.0312
March	3,080	558	1,501	92,293	.1392	.1605
April	558	334	423	25,170	.0392	.0437
May	521	65	382	23,488	.0354	.0408
June	416	156	276	16,423	.0256	.0285
July	139	4	48	2,951	.0045	.0052
August	24	4	12	738	.0011	.0013
September	5	1	2	119	.0002	.0002
October	6	0.5	4	246	.0004	.0005
November	46	5	9	536	.0008	.0009
December	52	8	31	1,906	.0029	.0033
The year	3,080	0.5	256	185,806	.0238	.3236

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 106; rating table on page 175 of same paper.

Estimated monthly discharge of Humboldt River near Oreana, Nev.

[Drainage area, 13,800 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	205	60	113	6,948	0.008	0.009
February	430	99	222	12,329	.016	.017
March	2,616	301	1,318	81,041	.096	.111
April	986	330	587	34,929	.043	.048
May	511	167	317	19,492	.023	.027
June	167	99	133	7,914	.010	.011
July	150	60	108	6,641	.008	.009
August	88	21	39	2,398	.003	.003
September	21	10	17	1,012	.001	.001
October	274	21	48	2,951	.003	.003
November	38	26	30	1,785	.002	.002
December	78	32	51	3,136	.004	.005
The year	2,616	10	249	170,576	.018	.246

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 107; rating table on page 175 of same paper.

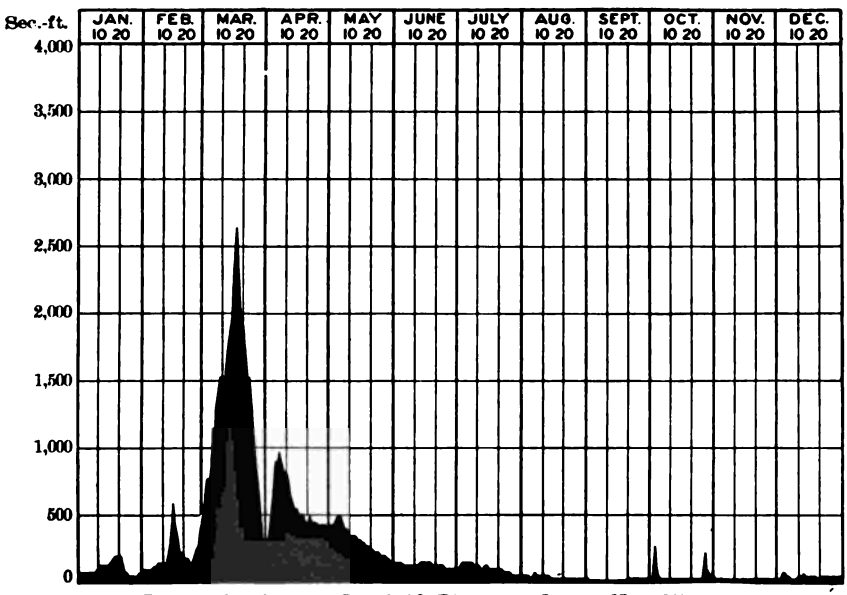


FIG. 57.—Discharge of Humboldt River near Oreana, Nev., 1901.

TRUCKEE RIVER.

Estimated monthly discharge of Truckee River at Tahoe, Cal.

[Drainage area, 519 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	117	85	102	6,262	0.196	0.226
February	117	30	81	4,502	.156	.163
March	30	30	30	1,845	.058	.067
April	30	0	9	565	.018	.020
May	0	0	0	0	.000	.000
June	178	0	30	1,765	.058	.064
July	293	156	225	13,809	.433	.499
August	555	293	419	25,760	.803	.931
September	390	117	326	19,395	.628	.701
October	308	251	282	17,308	.542	.625
November	293	189	247	14,678	.475	.530
December	189	100	111	6,841	.214	.247
The year	555	0	155	112,730	.299	4.073

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 111; rating table on page 175 of same paper.

Estimated monthly discharge of Truckee River at Nevada-California State line.

[Drainage area, 955 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	559	230	314	19,308	0.329	0.379
February	3,435	247	1,082	60,092	1.133	1.176
March	2,280	732	1,280	78,708	1.340	1.544
April	2,505	613	1,476	87,829	1.545	1.728
May	4,370	1,508	2,478	152,370	2.595	2.992
June	2,505	989	1,595	94,910	1.670	1.862
July	1,194	421	686	42,181	.718	.828
August	795	349	486	29,884	.509	.588
September	559	247	472	28,086	.494	.552
October	559	247	470	28,900	.492	.566
November	613	383	469	27,908	.491	.549
December	1,194	247	445	27,347	.466	.536
The year	4,370	230	938	677,521	.982	13.300

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 112; rating table on page 175 of same paper.

Estimated monthly discharge of Steamboat Creek at Steamboat Springs, Nev.

[Drainage area, 123 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	56.0	3.0	7.6	467	0.061	0.071
February	72.0	3.0	15.6	866	.126	.132
March	20.5	5.0	10.8	664	.087	.101
April	11.5	3.0	7.7	458	.062	.069
May	29.5	11.5	21.4	1,316	.174	.200
June	39.0	17.0	29.6	1,761	.240	.268

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 114; rating table on page 175 of same paper.

Estimated monthly discharge of Truckee River at Vista, Nev.

[Drainage area, 1,519 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,505	418	661	40,644	0.435	0.502
February	4,213	418	1,486	82,529	.978	1.019
March	2,209	938	1,328	81,657	.874	1.008
April	1,942	747	1,380	82,117	.908	1.014
May	4,213	1,410	2,145	131,894	1.412	1.628
June	1,942	854	1,263	75,155	.831	.928
July	995	146	425	26,133	.280	.323
August	492	128	315	19,369	.207	.227
September	467	251	329	19,577	.217	.242
October	720	370	477	29,330	.314	.362
November	882	467	557	33,144	.367	.409
December	1,287	322	510	31,357	.336	.387
The year	4,213	128	906	652,906	.597	8.0[illegible]

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 113; rating table on page 175 of same paper.

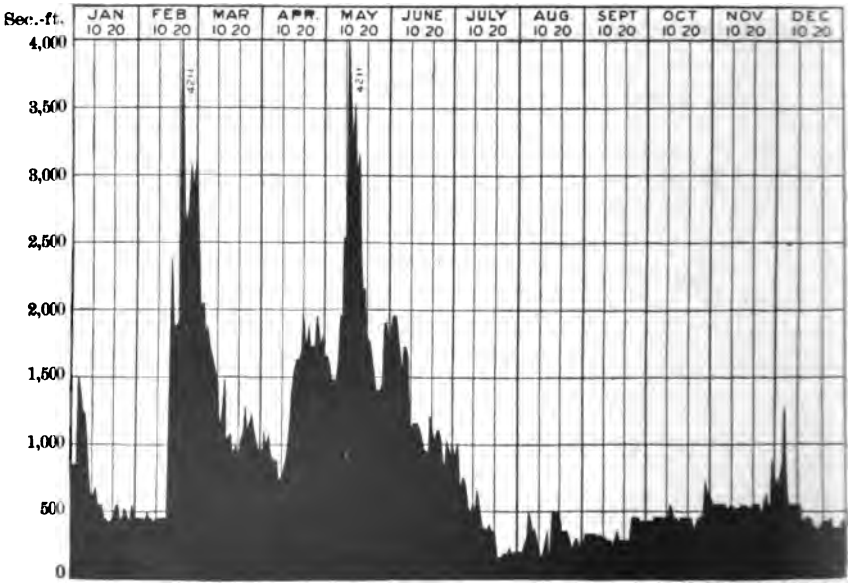


FIG. 58.—Discharge of Truckee River at Vista, Nev., 1901.

CARSON RIVER.

Estimated monthly discharge of East Fork of Carson River near Gardnerville, Nev.

[Drainage area, 381 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October			38	2,337	0.100	[a] 0.058
November	75	30	41	2,440	.108	.120
December	35	30	34	2,091	.089	.103
1901.						
January	86	14	34	2,091	.089	.103
February	2,267	14	664	36,877	1.743	1.815
March	927	219	464	28,531	1.218	1.256
April	927	261	582	34,632	1.527	1.704
May	3,162	856	1,822	112,033	4.782	5.513
June	2,008	1,141	1,492	88,780	3.916	4.369
July	1,512	313	741	45,562	1.945	2.242
August	626	85	259	16,026	.680	.789
September	220	85	139	8,271	.365	.407
October	271	102	137	8,424	.360	.415
November	332	122	196	11,663	.514	.574
December	1,213	134	280	17,217	.735	.847
The year	3,162	14	568	410,107	1.490	20.034

[a] Partial month.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 108; rating table on page 175 of same paper.

Estimated monthly discharge of West Fork of Carson River at Woodfords, Cal.

[Drainage area, 70 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October 18–31	.....	.....	44	1,222	0.63	0.33
November	60	37	48	2,856	.69	.77
December	71	37	53	3,259	.76	.87
1901.						
January	66	41	51	3,136	.73	.84
February	256	41	111	6,165	1.59	1.65
March	256	121	170	10,453	2.43	2.80
April	412	121	234	13,924	3.34	3.73
May	896	295	476	29,268	6.80	7.84
June	396	187	289	17,197	4.13	4.61
July	187	97	136	8,363	1.94	2.24
August	166	50	77	4,735	1.10	1.27
September	50	41	43	2,559	.61	.69
October	60	41	49	3,013	.70	.81
November	60	50	56	3,332	.80	.89
December	112	60	82	5,042	1.17	1.35
The year	896	41	148	107,187	2.11	28.72

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 109; rating table on page 175 of same paper.

Estimated monthly discharge of Carson River near Empire, Nev.

[Drainage area, 988 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October			70	4,304	0.071	0.082
November	550	46	109	6,486	.110	.123
December	113	68	93	5,718	.094	.109
1901.						
January	772	40	115	7,071	.116	.134
February	2,470	40	645	35,822	.653	.682
March	1,001	478	634	38,984	.642	.740
April	1,420	329	700	41,653	.709	.790
May	3,791	924	1,994	122,606	2.018	2.328
June	2,304	853	1,422	84,615	1.438	1.605
July	1,084	167	468	28,777	.474	.546
August	297	40	126	7,748	.128	.147
September	70	25	39	2,321	.040	.044
October	213	70	113	6,948	.114	.132
November	297	189	197	11,722	.199	.222
December	758	213	311	19,122	.315	.363
The year	3,791	25	563	407,389	.570	7.733

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 111; rating table on page 175 of same paper.

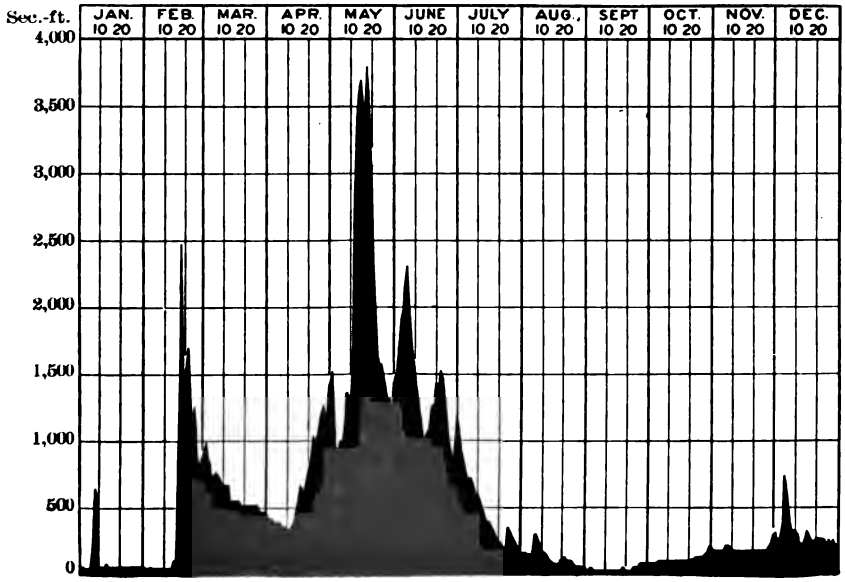


FIG. 59.—Discharge of Carson River near Empire, Nev., 1901.

SUSAN RIVER.

Estimated monthly discharge of Susan River near Susanville, Cal.

[Drainage area, 210 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	.....	.....	31	1,669	0.15	0.15
July	18	11	13	799	.06	.07
August	12	10	11	676	.05	.06
September	11	10	11	655	.05	.06
October	36	11	17	1,045	.08	.09
November	390	15	47	2,797	.22	.25
December	470	26	60	3,689	.29	.33
1901.						
January	52	36	43	2,644	.20	.23
February	1,070	36	308	17,105	1.47	1.53
March	770	197	363	22,320	1.73	1.99
April	730	134	371	22,076	1.77	1.97
May	590	168	420	25,825	2.00	2.31
June	156	15	56	3,332	.27	.30
July	24	9	18	1,107	.09	.10
August	13	5	10	615	.05	.06
September	9	4	6	369	.03	.03
October	16	7	10	615	.05	.06
November	101	10	19	1,131	.09	.10
December	470	11	61	1,783	.29	.33
The year	1,070	4	140	98,922	.67	9.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 116; rating table on page 175 of same paper.

BEAR RIVER.

Estimated monthly discharge of Bear River at Battlecreek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	522	497	503	30,928	0.11	0.13
February	1,650	497	663	36,821	.15	.16
March	1,650	1,070	1,217	74,830	.27	.31
April	2,568	1,070	1,619	96,337	.36	.40
May	2,925	2,466	2,726	167,614	.61	.70
June	2,415	737	1,425	84,793	.32	.36
July	704	400	487	29,944	.11	.13
August	434	400	418	25,702	.09	.10
September	474	400	436	25,944	.10	.11
October	578	474	505	31,051	.11	.13
November	578	497	561	33,384	.12	.13
December	704	522	614	37,753	.13	.15
The year	2,925	400	931	675,101	.21	2.81

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 117; rating table on page 176 of same paper.

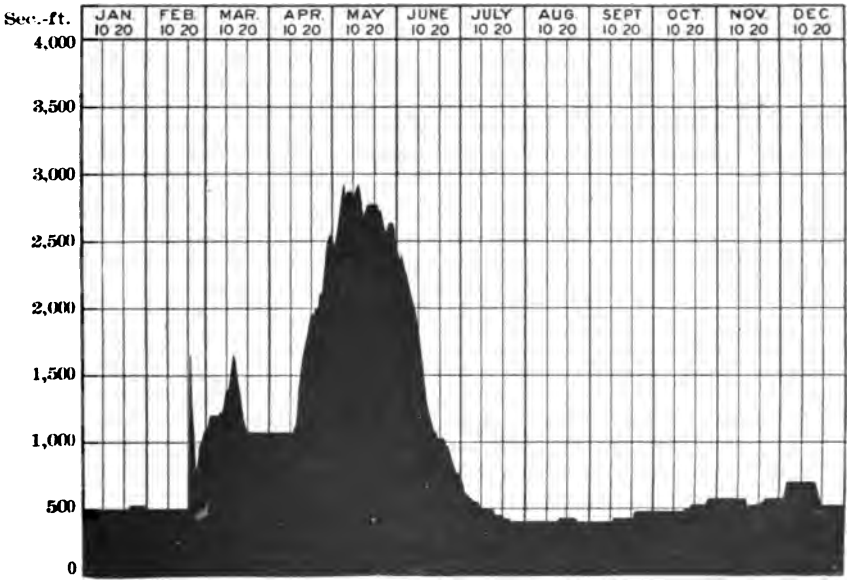


FIG. 60.—Discharge of Bear River at Battlecreek, Idaho, 1901.

Estimated monthly discharge of Logan River near Logan, Utah.

[Drainage area, 218 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	167	143	159	9,777	0.73	0.84
February	167	150	155	8,608	.71	.74
March	167	150	156	9,592	.72	.83
April	450	150	236	14,043	1.08	1.20
May	1,440	422	901	55,400	4.13	4.76
June	850	511	667	39,689	3.06	3.53
July 9–31			289	13,184	1.33	1.13
August	258	227	240	14,757	1.10	1.27
September	227	213	213	12,674	.98	1.09
October	213	188	197	12,113	.90	1.04

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66; rating table on page 176 of same paper.

Estimated monthly discharge of Blacksmith Fork at Hyrum, Utah.

[Drainage area, 286 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	124	108	115	7,071	0.40	0.46
February	128	108	113	6,276	.40	.42
March	147	112	119	7,317	.42	.48
April	147	112	132	7,855	.46	.51
May	514	112	187	11,498	.65	.75
June	347	147	187	11,127	.65	.73
July	147	128	133	8,178	.47	.54
August	147	128	134	8,239	.47	.54
September	128	120	122	7,261	.43	.48
October	293	120	131	8,056	.46	.53
November	120	120	120	7,141	.42	.47
December	120	112	119	7,317	.42	.48
The year	514	108	134	97,336	.47	6.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 119; rating table on page 176 of same paper.

Estimated monthly discharge of Bear River near Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,550	915	1,239	76,183	0.21	0.24
February	2,880	1,105	1,555	86,354	.26	.27
March	2,880	1,700	2,032	124,943	.34	.39
April	3,575	1,700	2,399	142,750	.40	.45
May	4,950	3,575	4,469	274,788	.74	.85
June	3,640	1,025	2,029	120,734	.34	.38
July	987	415	686	42,180	.11	.13
August	717	415	574	35,294	.10	.12
September	915	635	724	43,081	.12	.13
October	1,105	880	1,006	61,857	.17	.20
November	1,232	1,025	1,144	68,073	.19	.21
December	1,405	1,025	1,197	73,600	.20	.23
The year	4,950	415	1,588	1,149,837	.27	3.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Pap e No, 66, page 120; rating table on page 176 of same paper.

WEBER RIVER.

Estimated monthly discharge of Weber River near Uinta, Utah.

[Drainage area, 1,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	263	263	263	15,171	0.16	0.18
February	1,655	263	681	37,821	.43	.45
March	1,865	500	707	43,472	.44	.51
April	1,970	500	948	56,410	.59	.66
May	2,425	1,235	1,981	121,807	1.24	1.43
June	1,235	440	712	42,367	.45	.50
July	380	110	207	12,728	.13	.15
August	320	110	200	12,297	.13	.15
September	210	210	210	12,496	.13	.15
October	320	263	272	16,725	.17	.20

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 122; rating table on page 176 of same paper.

UTAH LAKE DRAINAGE.

Estimated monthly discharge of Spanish Fork near Mapleton, Utah.

[Drainage area, 670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	188	75	132	7,855	0.20	0.22
July	75	54	56	3,443	.08	.09
August	54	45	53	3,259	.08	.09
September	86	54	61	3,630	.09	.10
October	75	54	63	3,874	.09	.10
November	86	54	74	4,403	.11	.12
December	86	36	58	3,566	.09	.10
1901.						
January	200	15	41	2,521	.06	.07
February	372	15	91	5,054	.14	.15
March	141	75	97	5,964	.14	.16
April	224	86	131	7,795	.20	.22
May	385	176	271	16,663	.40	.46
June	188	86	133	7,914	.20	.22
July	86	64	77	4,735	.10	.12
August	164	64	99	6,087	.15	.17
September	86	75	75	4,463	.10	.11
October	119	75	82	5,042	.12	.14
November	97	75	82	4,879	.12	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 128; rating table on page 176 of same paper.

Estimated monthly discharge of Provo River near Provo, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	353	279	314	19,307	0.49	0.56
February	1,658	258	471	26,158	.74	.77
March	411	302	333	20,475	.52	.60
April	788	302	392	23,326	.61	.68
May	2,093	587	1,181	72,617	1.85	2.13
June	875	224	399	23,742	.62	.69
July	240	224	239	14,696	.37	.43
August	240	224	238	14,634	.37	.43
September	240	240	240	14,281	.38	.42
October	302	240	257	15,802	.40	.46
November 1–16	279	279	279	8,854	.44	.26

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 123; rating table on page 176 of same paper.

Estimated monthly discharge of American Fork near American Fork, Utah.

[Drainage area, 66 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	213	54	111	6,016	1.68	1.87
July	67	34	45	2,767	.68	.78
August	27	23	26	1,599	.39	.45
September	43	23	26	1,547	.39	.44
October	34	27	30	1,845	.45	.52
November	34	27	29	1,726	.44	.49
December	34	27	33	2,029	.50	.58
1901.						
January	34	34	34	2,091	.52	.60
February	43	27	36	1,999	.55	.57
March	43	34	36	2,213	.55	.59
April 10–30	.....	.....	125	5,206	1.89	1.48
May 1–18	.....	.....	582	20,779	8.82	5.90

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 124; rating table on page 176 of same paper.

SEVIER RIVER.

Estimated monthly discharge of Salina Creek near Salina, Utah.

[Drainage area, 255 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	27.0	15.0	19.6	1,205	0.077	0.089
February	24.7	15.0	19.4	1,088	.076	.079
March	21.0	13.5	14.6	898	.057	.066
April	33.7	15.0	22.9	1,363	.090	.100

NOTE.—Gage heights for 1901 are given in Water-Supply Paper No. 66, page 125.

Estimated monthly discharge of San Pitch River near Gunnison, Utah.

[Drainage area, 836 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	15	9	12	738	0.014	0.016
February	37	9	16	889	.019	.020
March	21	9	13	774	.016	.018
April 7–30			35	2,083	.042	.047
May	125	51	92	5,657	.110	.127
June	95	65	77	4,582	.092	.103
July	71	15	45	2,767	.054	.062
August	25	15	18	1,107	.022	.025
September	15	10	14	833	.017	.019
October	19	14	14	861	.017	.020
November	14	10	13	774	.016	.018
December	13	12	12	738	.014	.016
The year	125	9	30	21,803	.036	.491

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 125; rating table on page 176 of same paper.

Estimated monthly discharge of Sevier River near Gunnison, Utah.

[Drainage area, 3,986 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			118	7,255	0.029	0.033
February	164	94	125	6,942	.031	.032
March	81	29	56	3,443	.014	.016
April	74	19	45	2,678	.011	.012
May	239	51	122	7,501	.031	.036
June	129	8	41	2,440	.010	.011
July	21	5	9	553	.002	.002
August	59	14	24	1,476	.006	.006
September	17	9	12	714	.003	.003
October	12	7	8	476	.002	.002
November	41	17	34	2,023	.009	.009
December	154	41	81	4,980	.020	.023
The year	239	5	56	40,481	.014	.185

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 126; rating table on page 176 of same paper.

COLUMBIA RIVER DRAINAGE.

Next to the Colorado, Columbia River is the largest river in the arid region, its drainage basin including parts of Washington, Oregon, Idaho, and Montana and a large area in Canada. The Columbia and its numerous tributaries are of great importance, offering good sites for water-power development and an abundance of water for irrigation, while the main river is navigable for a considerable distance. But little has been accomplished at the present time in developing either of these resources.

In the following pages is published a report on the irrigation development in the valley of Snake River, the most important tributary of the Columbia, by D. W. Ross, State engineer of Idaho.

During 1901 gaging stations were maintained on the following tributaries of the Columbia: On Missoula, Blackfoot, and Bitterroot rivers near Missoula, Mont.; on Snake River at Montgomery Ferry, near Minidoka, Idaho; on Boise River, near Boise, Idaho; on Weiser River near Weiser, Idaho; on Spokane River at Spokane, Wash.; on Naches River near North Yakima, Wash.; on Yakima River at Union Gap and at Kiona, Wash.; on Palouse River, near Hooper,

Wash.; and on Umatilla River at Gibbon, Oreg., the results of measurements of which are given in the following pages.

MISSOULA RIVER.

Estimated monthly discharge of Blackfoot River near Bonner, Mont.

[Drainage area, 2,465 square miles.]

Month.	Discharge in second-feet.			Total in acre feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,060	550	673	41,381	0.27	0.31
February	1,310	450	580	32,212	.24	.25
March	3,988	550	1,017	62,533	.41	.47
April	2,950	585	1,186	70,572	.48	.54
May	12,302	3,899	8,552	525,842	3.47	4.00
June	7,676	2,650	3,698	220,046	1.50	1.67

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 130; rating table on page 177 of same paper.

Estimated monthly discharge of Missoula River at Missoula, Mont.

[Drainage area, 5,960 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March			2,090	128,509	0.35	0.40
April 1-10, 13-30			2,601	154,770	.44	.47
May	20,200	7,300	15,156	931,906	2.54	2.93
June	14,450	5,150	7,458	443,782	1.25	1.39
July	4,650	1,690	2,815	173,026	.47	.54
August	1,625	980	1,300	79,933	.22	.25
September	1,625	980	1,415	84,198	.24	.27
October	1,625	1,430	1,472	90,510	.25	.29
November	1,625	1,365	1,478	87,947	.25	.28
December 1-10			1,413	27,794	.24	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 131; rating table on page 177 of same paper.

A. TWIN FALLS OF SNAKE RIVER, IDAHO.

B. LOCATION OF DAM SITE NEAR TWIN FALLS, IDAHO.

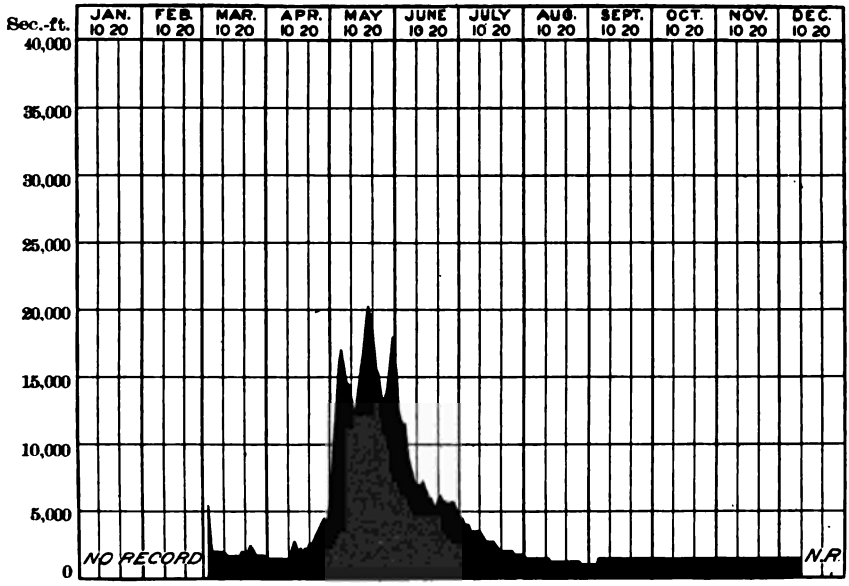


FIG. 61.—Discharge of Missoula River at Missoula, Mont., 1901.

Estimated monthly discharge of Bitterroot River at Missoula, Mont.

[Drainage area, 3,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			1,360	83,623	0.42	0.49
February			1,401	77,808	.43	.45
March	2,750	1,390	1,691	103,976	.52	.60
April (twenty-one days)			1,866	81,425	.57	.51
May	18,375	7,210	11,025	67,790	3.38	3.90
June	11,700	3,050	5,020	298,711	1.54	1.72
July	3,650	1,225	2,667	163,980	.82	.95
August	1,200	940	995	61,180	.31	.36
September	1,320	940	1,130	67,507	.35	.39
October	1,250	1,080	1,157	71,141	.36	.42
November	1,175	1,100	1,149	68,370	.35	.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 132.

SPOKANE RIVER.

Estimated monthly discharge of Spokane River at Spokane, Wash.

[Drainage area, 4,005 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,824	7,738	9,887	607,928	2.47	2.85
February	9,838	5,172	7,289	404,811	1.82	1.89
March	19,706	10,815	14,843	912,660	3.71	4.28
April	13,019	9,565	11,143	663,054	2.79	3.11
May	22,711	13,324	19,901	1,223,665	4.97	5.74
June	20,054	9,565	13,513	804,079	3.38	3.77
July	9,295	4,241	6,441	396,042	1.61	1.86
August	4,141	2,767	3,263	200,634	.82	.95
September	2,682	2,517	2,564	152,569	.64	.71
October	2,600	2,278	2,461	151,321	.62	.71
November	4,141	2,356	2,806	166,969	.70	.78
December	5,389	3,946	4,593	282,413	1.15	1.33
The year	22,711	2,278	8,225	5,966,145	2.06	27.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 133; rating table on page 177 of same paper.

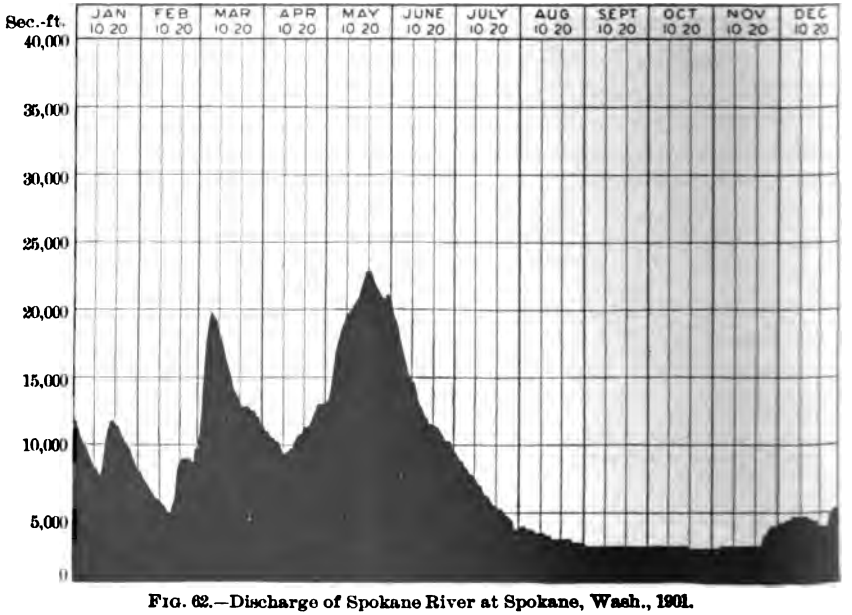


FIG. 62.—Discharge of Spokane River at Spokane, Wash., 1901.

SHOSHONE FALLS ON SNAKE RIVER, IDAHO.

SNAKE RIVER.

Estimated monthly discharge of Boise River near Boise, Idaho.

[Drainage area, 2,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,430	1,130	1,280	78,704	0.52	0.60
February	4,380	1,095	1,756	97,523	.72	.75
March	4,604	2,180	2,892	177,822	1.18	1.36
April	8,636	2,070	5,056	300,853	2.06	2.30
May	12,668	7,516	10,106	621,394	4.13	4.76
June	7,740	2,720	4,789	284,965	1.95	2.18
July	2,880	1,060	1,878	115,474	.77	.89
August	1,060	740	846	52,141	.35	.40
September	990	770	833	49,567	.34	.38
October	1,095	860	910	55,954	.37	.43
November	1,200	860	933	55,517	.38	.42
December	2,180	830	1,233	75,814	.50	.58
The year	12,668	740	2,708	1,965,728	.11	15.05

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 128; rating table on page 176 of same paper.

Estimated monthly discharge of Weiser River near Weiser, Idaho.

[Drainage area, 1,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,800	375	945	58,106	0.57	0.66
February	7,137	470	1,921	106,678	1.15	1.20
March	6,230	1,425	2,964	182,249	1.77	2.04
April	3,530	1,330	2,523	150,129	1.51	1.68
May	5,150	2,585	3,935	241,958	2.36	2.73
June	2,585	585	1,304	77,593	.78	.87
July	585	250	363	22,320	.22	.25
August	215	39	67	4,120	.04	.05
September	87	47	71	4,225	.04	.04
October	137	96	115	70,712	.07	.08
November	330	137	191	11,365	.11	.12
December	1,330	250	525	32,281	.31	.36
The year	7,137	39	1,244	961,736	.74	10.08

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 129; rating table on page 176 of same paper.

YAKIMA RIVER.

Estimated monthly discharge of Naches River near North Yakima, Wash.

[Drainage area, 1,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	4,030	910	1,559	95,859	1.56	1.80
February	4,600	830	1,621	90,026	1.62	1.69
March	9,100	1,690	3,427	210,718	3.43	3.96
April	2,780	1,550	2,199	130,850	2.20	2.46
May	8,800	3,250	5,628	346,052	5.63	6.49
June	6,700	2,570	4,026	239,564	4.03	4.50
July	2,780	1,090	1,937	119,101	1.94	2.24
August	1,090	430	683	41,996	.68	.78
September	470	390	405	24,099	.41	.46
October	430	370	380	23,365	.38	.44
November	6,400	430	1,101	65,514	1.10	1.23
December	4,030	750	1,600	98,380	1.60	1.84
The year	9,100	370	2,047	1,485,524	2.05	27.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 134; rating table on page 177 of same paper.

Estimated monthly discharge of Yakima River at Union Gap, Wash.

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	8,650	2,600	4,371	268,762	1.32	1.52
February	10,750	1,950	3,720	206,598	1.13	1.18
March	20,900	4,250	8,356	513,790	2.53	2.92
April	6,300	4,000	5,272	313,706	1.60	1.79
May	18,100	6,900	11,482	706,001	3.48	4.05
June	13,200	6,300	8,713	518,460	2.64	2.95
July	6,300	2,600	4,508	277,186	1.37	1.58
August	2,425	1,050	1,544	94,937	.47	.54
September	1,250	850	1,023	60,873	.31	.35
October	1,050	750	895	55,031	.27	.31
November	5,100	850	2,710	161,256	.82	.92
December	12,500	2,600	5,800	356,628	1.76	1.96
The year	20,900	750	4,866	3,533,228	1.48	20.07

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 135; rating table on page 177 of same paper.

THOUSAND SPRINGS ON SNAKE RIVER, IDAHO.

Estimated monthly discharge of Yakima River at Kiona, Wash.

[Drainage area, 5,230 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	13,545	4,935	6,886	423,404	1.32	1.52
February	14,745	3,592	6,299	349,828	1.20	1.25
March	24,045	6,995	11,779	724,263	2.26	2.61
April	8,782	5,833	7,420	441,521	1.42	1.58
May	20,745	8,472	14,037	863,101	2.68	3.09
June	15,345	5,228	8,773	522,030	1.68	1.87
July	5,150	1,832	3,476	213,731	.66	.76
August	1,769	525	1,053	64,746	.20	.23
September	519	465	481	28,620	.09	.10
October	917	525	643	39,537	.12	.14
November	6,248	940	3,202	190,532	.61	.68
December	9,570	1,769	4,316	265,381	.83	.96
The year	24,045	465	5,697	4,126,694	1.09	14.79

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 136; rating table on pape 177 of same paper.

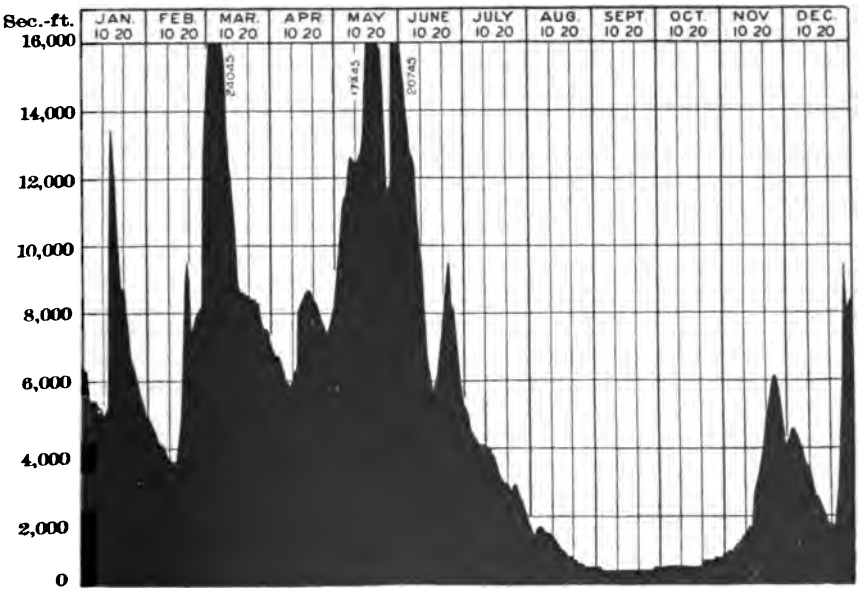


FIG. 63.—Discharge of Yakima River at Kiona, Wash., 1901.

DISCHARGE MEASUREMENTS OF ARTESIAN WELLS IN MOXEE VALLEY NEAR NORTH YAKIMA, WASH.[a]

No. 1.—Clarke's No. 1 (Pecks), sec. 6, T. 12, R. 20. Weir measurement, April 20, 1899; discharge, 1,435 second-feet.

This well was closed in December, 1900, and partly opened in April. Approximate measurement, with Price meter in flume, April 11, 1901, discharge, 1.34 second-feet. Barom. el., 1,049.

No. 2.—Clarke's No. 2, NE. ¼ SW. ¼ sec. 31, T. 13, R. 20. Weir measurement, March 3, 1899, 1,046 second-feet.

This well remained open during the winter. A measurement over an 18-inch weir, April 11, 1901, gave a discharge of 0.52 second-foot. Barom. el., 1,085.

No. 2a.—Clarke's No. 2a, NE. ¼ SW. ¼ sec. 31, T. 13, R. 20. Weir measurement, March 3, 1899, 0.469 second-foot.

This well remained open during the winter. A weir measurement, April 11, 1901, gave a discharge of 0.15 second-foot. Barom. el., 1,076.

No. 3.—Meigs, NW. ¼, SE. ¼, sec. 32, T. 13, R. 20. Discharge 18 cubic feet per minute.

This well has ceased to flow and is now abandoned.

No. 4.—Yakima Land Company, No. 4, sec. 4, T. 12, R. 20. No flow.

Well abandoned.

No. 5.—Yakima Land Company, No. 1, sec. 3, T. 12, R. 20. No flow.

Well abandoned.

No. 6.—Yakima Land Company, No. 3, sec. 3, T. 12, R. 20. Original yield estimated at 30 cubic feet per minute. No flow.

Well abandoned.

No. 7.—Bradford (now Hill), sec. 9, T. 12, R. 20. Measurement over 2-foot weir, March 19, 1901, gave a discharge of 0.904 second-foot.

No. 8.—Dickson, sec. 8, T. 12, R. 20. Yield unknown.

Abandoned since December 1, 1900.

No. 9.—Gano, sec. 8, T. 12, R. 20. No measurement obtainable. Partly shut down from December 1, 1900. April 1, 1901, still partly closed.

No. 10.—Ellens, SE. ¼ NE. ¼ sec. 7, T. 12, R. 20. Measurement made March 23, 1901, showed a discharge of 0.13 second-foot.

This well has been closed down since the summer of 1900. Barom. el., 995 feet. Cased 300 feet.

No. 11.—Longevin, sec. 8, T. 12, R. 20. Measurement on April 9, 1901, gave a discharge of 0.4 second-foot. Barom. el., 995.

No. 12.—Haines (Patterson), sec. 8, T. 12, R. 20. Measurement on March 22, 1901, gave a discharge of 0.984 second-foot.

No. 13.—Spratt (Sauvé), sec. 8, T. 12, R. 20. Weir measurement made March 22, 1901, gave discharge of 0.475 second-foot.

There is said to be 65 feet of sandstone below the first flow. The well was closed September 15, 1900, to be opened April 1, 1901.

No. 14.—Steinweg No. 1, SE. ¼ SE. ¼ sec. 10, T. 12, R. 20. A weir measurement on July 21, 1899, gave a discharge of 0.312 second-foot.

The well has ceased to flow and is abandoned.

No. 15.—Steinweg No. 2, sec. 10, T. 12, R. 20. A weir measurement, July 21, 1899, gave a discharge of 0.104 second-foot.

The well has ceased to flow and is abandoned. (Water rises to within 2 feet of the surface.)

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[a] As reported by Sydney Arnold, April 18, 1901. (See also Water-Supply Paper No. 55 on the Geology and Water Resources of Yakima County, Wash., by George Otis Smith.)

No. 16.—Steinweg No. 3, sec. 10, T. 12, R. 20. A weir measurement, July 21, 1899, gave a discharge of 0.1312 second-foot.

The well is now abandoned, having ceased to flow.

No. 17.—Yakima Land Company, sec. 14, T. 12, R. 20. No flow; well is abandoned. Seventy-five feet of the bore is in rock.

No. 18.—Ellens, SW. ¼ SE. ¼ sec. 5, T. 12, R. 20. Discharge, August, 1898, by weir measurement, 1.9 second-feet; March 26, 1891, approximate measurement by current meter, 2 second-feet. This is the largest in the valley. The well was closed down during the winter of 1900–1901.

No. 19.—Regimbau, SW. ¼ SE. ¼ sec. 5, T. 12, R. 20. Approximate measurement, with Price current meter, April 10, 1901, gave a discharge of 1.09 second-feet.

No. 20.—Buwalda, NE. ¼ SW. ¼ sec. 32, T. 13, R. 20. A weir measurement on March 3, 1899, gave a discharge of 0.8 second-foot; and on April 10, 1901, a discharge of 0.05 second-foot. The water has fallen below surface level, but is raised to an elevation of 20 feet by a small centrifugal pump and 6-horsepower gasoline engine.

No. 21.—Clarke's No. 4, NW. ¼ SE. ¼ sec. 31, T. 13, R. 20. A weir measurement on April 10, 1901, gave a discharge of 0.197 second-foot.

No. 22.—Alwardt, SE. ¼ SW. ¼ sec. 9, T. 12, R. 20. Weir measurement, March 21, 1890, gave a discharge of 0.64 second-foot.

No. 23.—Talent, H. H., NW. ¼ SW. ¼ sec. 5, T. 12, R. 20. Measurement made March 26, 1891, gave a discharge of 0.35 second-foot.

No. 24.—Clarke's No. 5, NE. ¼ sec. 31, T. 13, R. 20. No flow. Abandoned. Lost drill.

No. 25.—Conrad, sec. 5, T. 12, R. 20. Commenced December 20, 1900. In progress. Depth, 347 feet, March, 1891.

No. 26.—Longevin, sec. 8, T. 12, R. 20. Weir measurement, April 10, 1901, showed a discharge of 0.807 second-foot.

No. 27.—Buwalda No. 2, NW. ¼ NW. ¼ sec. 5, T. 12, R. 20. Measurement, April 10, 1901, with Price current meter, gave an approximate discharge of 0.566 second-foot.

No. 28.—Peck, J. W., NW. ¼ NE. ¼ sec. 6, T. 12, R. 20. Measurement with current meter on April 11, 1901, gave an approximate discharge of 1.10 second-feet.

No. 29.—Ryan, Robert, SW. ¼ SW. ¼ sec. 10, T. 12, R. 20. A weir measurement on March 21, 1891, gave a discharge of 0.485 second-foot.

No. 30.—Patterson, NW. ¼ SW. ¼ sec. 8, T. 12, R. 20. Commenced January 12, 1901. In progress. Depth, 640 feet March 21, 1901.

No. 31.—Gano, NE. ¼ SW. ¼ sec. 30, T. 13, R. 20. Measurement, March 29, 1891, gave a discharge of 632 second-feet.

No. 32.—Ellens, SE. ¼ NE. ¼ sec. 8, T. 12, R. 20. Depth, 676 feet. Some water. Well abandoned.

No. 33.—Hill, SW. ¼ SW. ¼ sec. 4, T. 12, R. 20. A trifling flow.

Wide Hollow.—Wilson, SW. ¼ SE. ¼ sec. 29, T. 13, R. 18. Discharge estimated at 0.75 second-foot. Well closed during winter of 1900–1901. Still closed.

Mabton.—Terrill and Hoover, SE. ¼ SE. ¼ sec. 7, T. 8, R. 23. Abandoned.

Sunnyside.—Turner, NE. ¼ NW. ¼ sec. 8, T. 10, R. 23. Abandoned.

Selah Valley.—Parker, sec. 23, T. 14, R. 20. Work temporarily discontinued.

Wenas Valley.—Arlington and Stoffer. Abandoned.

Warm Springs (10 miles east of Ellensburg).—John P. Clerf. Work in progress.

PALOUSE RIVER.

Estimated monthly discharge of Palouse River near Hooper, Wash.

[Drainage area, 2,210 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,770	320	1,082	66,530	0.490	0.565
February	4,892	166	1,526	84,750	.690	.719
March	4,859	735	2,097	128,939	.949	1.094
April	1,328	446	861	51,233	.390	.435
May	410	166	248	15,249	.112	.129
June	484	100	176	10,473	.080	.089
July	131	16	73	4,489	.033	.038
August	16	2	9	553	.004	.005
September	10	2	7	417	.003	.003
October	10	7	8	492	.004	.005
November	86	10	23	1,369	.010	.011
December	347	19	74	4,550	.033	.038
The year	4,892	2	515	369,044	.233	3.131

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 137; rating table on page 177 of same paper.

UMATILLA RIVER.

Estimated monthly discharge of Umatilla River at Gibbon, Oreg.

[Drainage area, 358 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,735	334	811	49,866	2.30	2.65
February	4,155	264	1,201	66,700	3.40	3.54
March	3,556	1,114	1,655	101,762	4.69	5.41
April	2,017	1,081	1,472	87,590	4.17	4.65
May	1,884	544	1,266	77,843	3.59	4.14
June	498	249	350	20,826	.99	1.10
July	233	124	181	11,129	.51	.59
August	124	88	98	6,026	.28	.32
September	159	88	125	7,438	.35	.39
October	188	159	166	10,207	.47	.54
November	203	172	181	10,771	.51	.57
December	617	203	398	24,472	1.13	1.30
The year	4,155	88	659	474,630	1.87	25.30

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 137; rating table on page 177 of same paper.

NORTHERN PACIFIC COAST DRAINAGE.

The measurement of four streams in that part of the State of Washington located between Puget Sound and the Pacific Ocean and known as the Olympic Peninsula has been continued during the year. The streams measured are Dungeness, Elwha, Kalawa, and Soleduck rivers, all of which head in the Olympic Mountains, the first two flowing northwardly into the Strait of San Juan de Fuca, and the last two flowing westwardly into the Pacific Ocean. The work of stream gaging at these stations was brought to a close at the end of 1901, several years' records having been obtained which give a fair indication of the regimen of these streams, and for the further reason that owing to the turbulent character of the streams much difficulty has been experienced in making accurate measurements.

The station on White River, at Buckley, Wash., was also maintained during 1901. This stream rises in central Washington and flows into Admiralty Sound.

ELWHA RIVER.

Estimated monthly discharge of Elwha River at McDonald, Wash.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	11,440	985	1,935	118,978	10.29	11.86
February	11,212	645	1,807	100,354	9.61	10.01
March	7,000	685	1,561	95,982	8.30	9.57
April	1,300	625	957	56,944	5.09	5.68
May	8,053	1.071	2,445	150,337	13.00	14.99
June	5,947	1.226	2,380	141,620	12.66	14.13
July	2,100	1,340	1,641	100,901	8.73	10.06
August	1,420	873	1,173	72,125	6.24	7.20
September	929	605	690	41,059	3.67	4.10
October	1,900	460	664	40,838	3.53	4.07
November	23,848	795	4,036	240,159	21.47	23.95
December	7,468	1,071	2,306	141,790	12.26	14.14
The year	23,848	460	1,800	1,301,087	9.57	129.76

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 139; rating table on page 177 of same paper.

KALAWA RIVER.

Estimated monthly discharge of Kalawa River near Forks, Wash.

[Drainage area, 213 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	11,710	314	1,723	105,943	8.09	9.33
February	5,212	300	1,151	65,034	5.40	5.62
March	5,212	620	1,372	84,361	6.44	7.42
April	2,438	566	997	59,325	4.68	5.22
May	5,022	314	949	58,352	4.46	5.14
June	909	314	478	28,443	2.24	2.50
July	300	147	180	11,067	.84	.97
August	158	0	48	2,951	.23	.27
September	170	0	41	2,440	.19	.21
October	2,704	0	199	12,236	.93	1.07
November	8,708	762	2,449	145,726	11.50	12.83
December	6,542	566	2,086	128,263	9.79	11.29
The year	11,710	0	973	704,141	4.57	61.87

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 140; rating table on page 177 of same paper.

SOLEDUCK RIVER.

Estimated monthly discharge of Soleduck River near Quillayute, Wash.

[Drainage area, 272 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,365	1,180	3,089	189,935	11.36	13.10
February	8,125	730	2,071	115,017	7.61	7.92
March	8,665	1,060	2,116	130,108	7.78	8.97
April	4,075	1,263	2,146	125,911	7.89	8.80
May	4,750	986	1,810	111,293	6.65	7.67
June	2,185	861	1,262	75,094	4.64	5.27
July	833	530	671	41,258	2.47	2.85
August	506	276	374	23,006	1.38	1.59
September	276	201	236	14,043	.87	.97
October	3,535	155	368	22,527	1.35	1.56
November	12,715	1,915	4,286	255,035	15.76	17.59
December	8,800	1,180	3,587	220,556	13.19	15.21
The year	12,715	155	1,835	1,323,783	6.75	91.50

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 141; rating table on page 177 of same paper.

SAN FRANCISCO BAY DRAINAGE.

Sacramento River, rising in northern California and flowing south, and the San Joaquin, rising in the southern sierras and flowing northeast, drain the western slope of the Sierra Nevada, traverse what is often called the Valley of California, and meet near Suisun Bay, finally discharging their waters into the Pacific Ocean through San Francisco Bay. Systematic measurements of discharge were made during 1901 of Sacramento River at Jellys Ferry, and of two of its tributaries, Stony Creek at Julian's ranch, near Fruto, and Cache Creek near the town of Lower Lake.

Stations were maintained during 1901 in the San Joaquin River drainage as follows: On Mokelumne River at Electra, on Stanislaus River near Oakdale, on Tuolumne River at Lagrange and at several points on its headwaters, on Merced River above Merced Falls, on San Joaquin River at Herndon, on King River near Red Mountain and near Kingsburg. Stations were maintained also on Tule River near Portersville and on Kern River at first point of measurement, near Bakersfield, both these streams belonging strictly to the above drainage.

SACRAMENTO RIVER.

Estimated monthly discharge of Sacramento River at Jellys Ferry, Cal.

[Drainage area, 9,134 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	74,240	8,915	20,983	1,290,194	2.30	2.66
February	101,880	9,800	34,138	1,895,928	3.74	3.89
March	46,100	12,200	20,628	1,268,366	2.26	2.61
April	16,700	9,200	10,870	646,810	1.19	1.33
May	13,700	7,530	9,804	602,824	1.07	1.23
June	7,265	4,965	5,596	332,985	.61	.68
July	4,760	3,980	4,365	268,393	.48	.55
August	3,980	3,805	3,850	236,727	.42	.48
September	5,380	3,630	3,922	233,375	.43	.48
October	5,380	3,980	4,194	257,879	.46	.53
November	44,100	4,360	7,745	460,859	.85	.94
December	61,800	5,380	12,149	747,013	1.33	1.53
The year	101,880	3,630	11,520	8,241,353	1.26	16.91

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 143; rating table on page 177 of same paper.

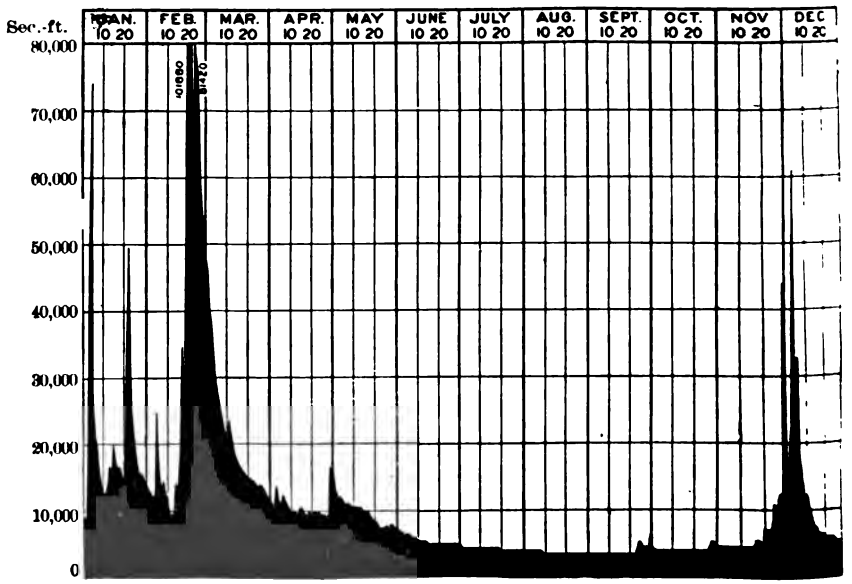

FIG. 64.—Discharge of Sacramento River at Jellys Ferry, Cal., 1901.

Estimated monthly discharge of Stony Creek near Fruto, Cal.

[Drainage area, 760 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	------	------	------	------	------	------
February	10,385	725	2,707	150,339	3.56	3.71
March	2,215	435	893	54,908	1.18	1.36
April	630	225	361	21,481	.48	.54
May	555	225	349	21,459	.46	.53
June	195	5	66	3,927	.09	.10
July	15	0	7	430	.01	.01
August	10	2	4	246	.01	.01
September	725	5	85	2,083	.05	.06
October	340	0	130	7,993	.17	.20
November	1,125	35	161	9,580	.21	.23
December	3,875	77	425	26,132	.56	.64
The year	10,385	0	428	298,578	.57	7.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 143; rating table on page 178 of same paper.

Estimated monthly discharge of Cache Creek near Lower Lake, California.

[Drainage area, 500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,020	155	535	32,896	1.07	1.23
February	2,520	615	909	50,483	1.82	1.89
March	1,330	805	1,079	66,345	2.16	2.49
April	805	530	654	38,916	1.31	1.46
May	570	380	481	29,576	.96	1.10
June	415	255	327	19,458	.65	.72
July	255	155	199	12,236	.40	.46
August	155	86	114	7,010	.23	.26
September	86	40	55	3,273	.11	.12
October	50	16	31	1,906	.06	.07
November	62	16	26	1,547	.05	.06
December	74	40	62	3,812	.12	.14
The year	2,520	16	373	267,458	.75	10.00

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 144; rating table on page 178 of same paper.

MOKELUMNE RIVER.

Estimated monthly discharge of Mokelumne River at Electra, Cal.

[Drainage area, 537 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	4,600	330	1,000	61,488	1.86	2.14
February	13,210	610	3,302	183,384	6.15	6.42
March	4,020	1,130	2,004	123,221	3.73	4.30
April	3,160	950	2,040	121,388	3.80	4.24
May	9,980	1,960	4,627	284,503	8.62	9.93
June	6,790	1,350	3,833	228,145	7.14	7.97
July			[a] 260	[a] 15,987	[a] .49	[a] .56
August			[a] 190	[a] 11,683	[a] .36	[a] .42
September			[a] 60	[a] 3,570	[a] .11	[a] .12
October			[a] 76	[a] 4,673	[a] .14	[a] .16
November			[a] 210	[a] 12,496	[a] .39	[a] .44
December			[a] 1,467	[a] 45,467	[a] 2.73	[a] 3.15
The year			[a] 1,589	[a] 1,096,005	[a] 2.96	[a] 39.85

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 145; rating table on page 178 of same paper.

SAN JOAQUIN RIVER.

Estimated monthly discharge of Tuolumne River at Hetch Hetchy Valley dam site, California.

[Drainage area, 400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	7,620	1,550	3,476	206,836	8.69	9.70
July	3,650	1,200	2,159	132,752	5.40	6.21
August	1,122	127	427	26,255	1.07	1.23
September	147	86	109	6,486	.27	.30

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 147.

Estimated monthly discharge of Eleanor Creek at Eleanor Trail Crossing, California.

[Drainage area, 81 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	1,834	374	824	49,031	10.10	11.35
July	510	138	275	16,909	3.40	3.92
August	122	18	52	3,197	.64	.74
September	18	5	8	476	.01	.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 147.

Estimated monthly discharge of Cherry River at Eleanor Trail Crossing, California.

[Drainage area, 130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	[a] 1,950	750	1,202	71,525	9.25	10.32
July	1,630	218	653	40,145	5.02	5.78
August	206	17	93	5,718	.72	.83
September	145	4	32	1,904	.25	.28

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 148.

Estimated monthly discharge of Tuolumne River at Lagrange, Cal.

[Drainage area, 1,501 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	18,280	560	3,351	206,145	2.23	2.58
February	19,240	1,440	7,203	400,090	4.80	5.00
March	7,080	2,080	3,719	228,733	2.48	2.86
April	7,080	1,740	3,960	235,696	2.64	2.94
May	13,160	4,075	8,035	494,114	5.36	6.18
June	13,160	4,900	9,387	558,566	6.26	6.98
July	9,960	1,440	3,700	227,566	2.47	2.85
August	2,080	200	784	48,206	.52	.60
September	350	55	175	10,413	.12	.13
October	1,590	0	211	12,974	.14	.16
November	1,300	300	574	34,155	.38	.43
December	5,800	200	1,339	82,332	.89	1.02
The year	19,240	0	3,537	2,538,990	2.36	31.73

Mining Company's canal flows 10 second-feet continuously from January 1 to March 31, 1901, and 7 second-feet continuously from April 1 to July 28, 1901.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 149; rating table on page 178 of same paper.

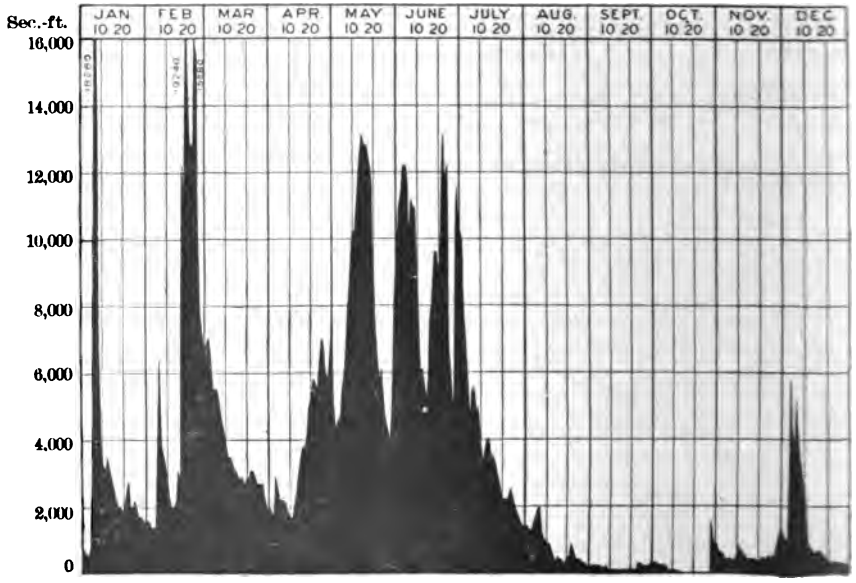

FIG. 65.—Discharge of Tuolumne River at Lagrange, Cal., 1901.

Estimated monthly discharge of Merced River above Merced Falls, Cal.

[Drainage area, 1,090 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	5,000	1,090	2,687	133,240	1.55	1.44
May	9,450	2,700	5,419	333,201	4.97	5.73
June	8,220	3,380	5,390	320,678	4.94	5.50
July	4,560	1,090	2,096	128,878	1.92	2.21
August	2,090	220	704	43,287	.65	.75
September	250	130	183	10,889	.17	.19
October	990	150	265	16,294	.24	.28
November	730	0	399	23,742	.37	.41
December	2,090	220	577	35,478	.53	.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 150; rating table on page 178 of same paper.

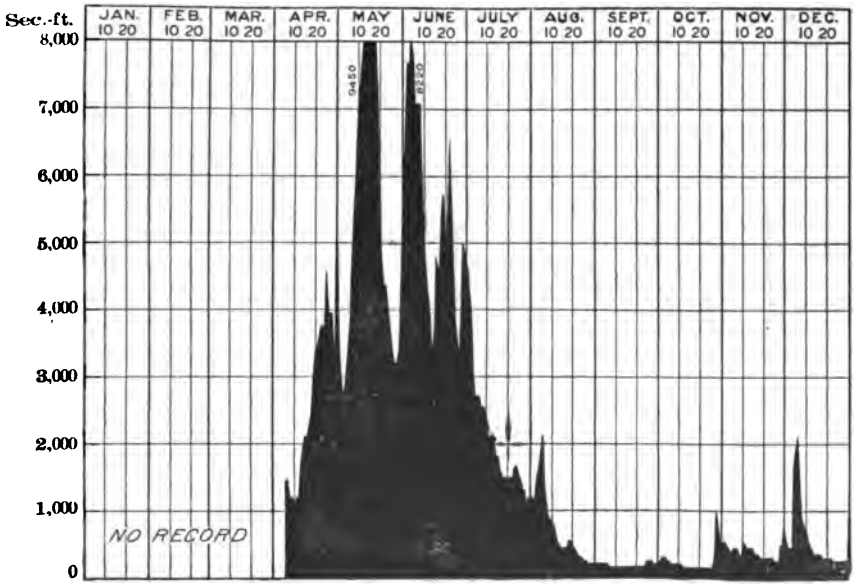

FIG. 66.—Discharge of Merced River above Merced Falls, Cal., 1901.

Estimated monthly discharge of San Joaquin River at Herndon, Cal.

[Drainage area, 1,637 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	21,372	810	3,506	215,576	2.14	2.47
February	12,940	1,550	4,983	276,742	3.04	3.17
March	6,830	2,480	4,191	257,695	2.56	2.95
April	12,400	1,930	4,680	278,479	2.86	3.18
May	17,870	4,775	10,935	672,367	6.68	7.71
June	15,662	7,882	11,998	713,930	7.33	8.17
July	14,294	3,110	3,466	213,116	2.12	2.45
August	5,850	500	2,373	145,910	1.45	1.67
September	500	360	399	23,742	.24	.27
October	2,480	340	489	30,067	.30	.35
November	1,550	500	702	41,772	.43	.48
December	2,060	460	872	53,617	.53	.61
The year	21,372	340	4,050	2,923,013	2.47	33.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 151; rating table on page 178 of same paper.

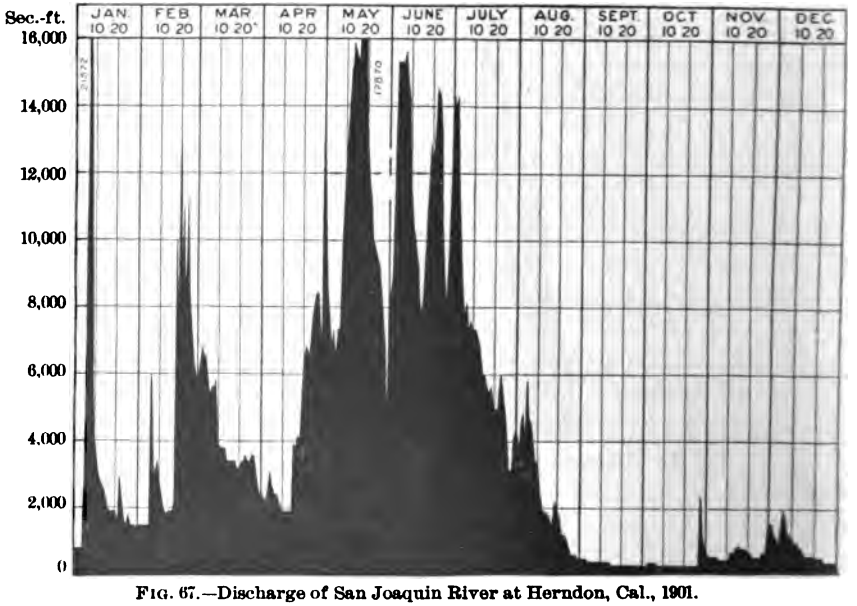

FIG. 67.—Discharge of San Joaquin River at Herndon, Cal., 1901.

Estimated monthly discharge of King River near Red Mountain, California.

[Drainage area, 1,742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	43,930	520	4,337	266,672	2.49	2.87
February	7,040	1,040	3,318	190,392	1.90	2.00
March	4,490	2,034	2,965	182,311	1.70	1.96
April	10,840	1,642	4,492	267,293	2.58	2.87
May	21,830	5,548	11,093	682,082	6.37	7.36
June	21,180	7,040	14,363	854,658	8.25	9.20
July	13,240	3,280	6,258	384,789	3.59	4.14
August	6,260	728	2,292	140,930	1.32	1.52
September	780	440	534	31,775	.31	.35
October	2,034	360	535	32,896	.31	.36
November	1,450	480	694	41,296	.40	.45
December	1,170	440	667	41,073	.38	.44
The year	43,930	360	4,296	3,116,167	2.47	33.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 152; rating table on page 178 of same paper.

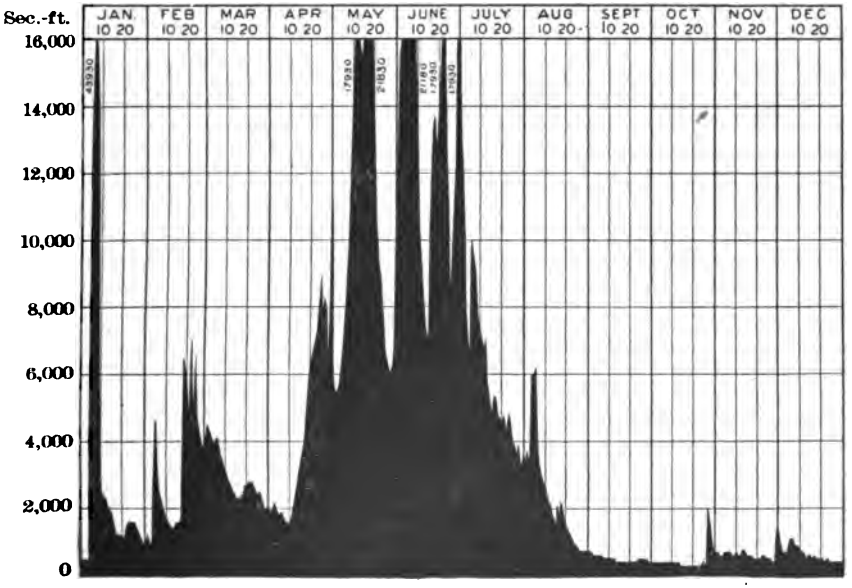

FIG. 68.—Discharge of King River near Red Mountain, California, 1901.

TULE RIVER.

Estimated monthly discharge of Tule River near Portersville, Cal.

[Drainage area, 437 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	875	298	418	25,702	0.96	1.10
June	408	126	240	14,281	.55	.61
July	126	30	61	3,751	.14	.16
August	30	18	19	1,168	.04	.04
September	23	10	17	1,012	.04	.04
October	109	18	29	1,783	.07	.08
November	71	35	43	2,559	.10	.11
December	64	39	50	3,074	.11	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 157; rating table on page 178 of same paper.

KERN RIVER.

Estimated monthly discharge of Kern River near Bakersfield, Cal.

[Drainage area, 2,345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,049	226	493	30,313	0.21	0.24
February	1,963	342	860	47,762	.37	.39
March	1,658	901	1,270	78,089	.54	.62
April	2,632	637	1,398	83,187	.60	.67
May	4,295	2,091	3,032	186,430	1.29	1.49
June	4,212	2,455	3,324	197,792	1.42	1.58
July	3,856	1,120	1,864	114,613	.80	.92
August	1,804	505	968	59,520	.41	.47
September	526	249	345	20,529	.15	.17
October	756	259	317	19,492	.14	.16
November	421	343	377	22,433	.16	.18
December	457	268	323	19,860	.14	.16
The year	4,295	226	1,216	880,020	.52	7.05

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 66, page 159.

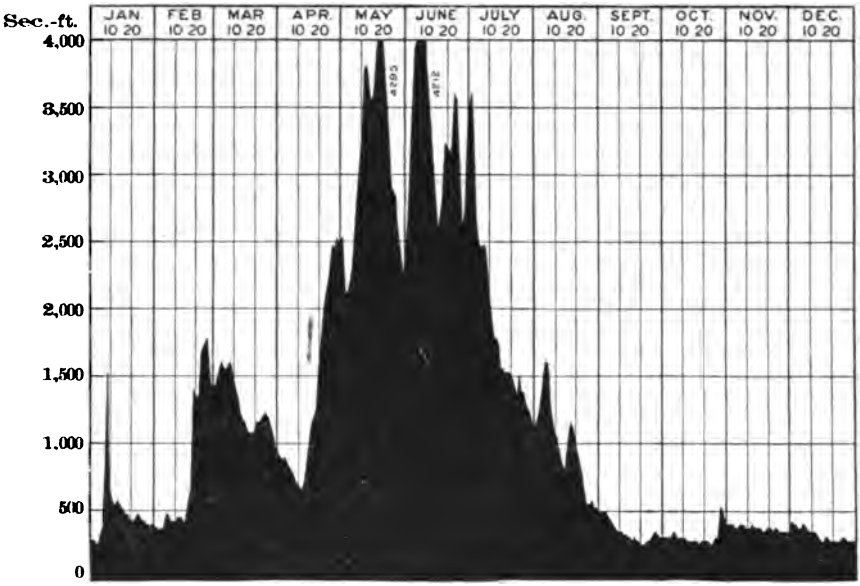

FIG. 69.—Discharge of Kern River near Bakersfield, Cal., 1901.

SOUTHERN CALIFORNIA DRAINAGE.

Under this head have been grouped all of the streams of southern California which do not drain directly or indirectly into San Francisco Bay. The measurements made on Salinas River and tributaries were brought to a close during 1901, the object for which the stations had been established, that is, furnishing the necessary data for computing the water supply available for the reservoir sites surveyed in the Salinas basin, having been accomplished. Measurements were continued on Mohave River at Victorville, on Santa Ana River below Warmsprings, and on San Gabriel River near Azusa. Records were also obtained of the flow of Lytle Creek, and of Mill Creek at Crafton headworks. Results for 1901 are given in the following pages.

SALINAS RIVER.

Estimated monthly discharge of Nacimiento Creek near Bryson, Cal.

[Drainage area, 171 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
March	365	110	184	11,314	1.08	1.25
April	670	87	99	5,891	.58	.64

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 154.

Estimated monthly discharge of San Antonio Creek near Jolon, Cal.

[Drainage area, 161 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,700	64	523	32,158	3.25	3.75
February	1,700	110	509	28,268	3.17	3.30
March	400	84	171	10,514	1.06	1.22
April	740	39	83	4,939	.52	.58

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 154; rating table on page 178 of same paper.

Estimated monthly discharge of San Lorenzo Creek near King City, Cal.

[Drainage area, 235 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,540	9	171	10,514	0.73	0.84
February	9,200	9	725	40,264	3.09	3.21
March	27	9	17	1,045	.07	.08
April	27	6	8	476	.03	.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 155; rating table on page 178 of same paper.

Estimated monthly discharge of Arroyo Seco near Piney, Cal.

[Drainage area, 215 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	4,500	105	888	54,601	4.13	4.77
February	2,860	160	931	51,705	4.33	4.51
March	610	105	246	15,126	1.14	1.31
April	2,500	95	195	11,603	.91	.91

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 156; rating table on page 178 of same paper.

Estimated monthly discharge of Salinas River near Salinas, Cal.

[Drainage area, 4,084 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	35,162	380	4,921	302,580	1.20	1.38
February	20,927	540	4,131	231,701	1.01	1.05
March	1,772	430	1,063	65,361	.26	.30
April	405	160	270	16,066	.07	.08
May	2,012	160	533	32,773	.13	.15
June	160	30	56	3,332	.01	.01
July	30	25	27	1,660	.01	.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 156; rating table on page 178 of same paper.

MOHAVE RIVER.

Estimated monthly discharge of Mohave River at Victorville, Cal.

[Drainage area, 400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	44	44	44	2,705	0.11	0.13
February	60	44	49	2,721	.12	.12
March	80	44	57	3,505	.14	.16
April	44	33	35	2,083	.09	.10
May	33	33	33	2,029	.08	.09
June	33	25	30	1,785	.08	.09
July	29	25	26	1,599	.06	.07
August	29	29	29	1,783	.07	.08
September	29	29	29	1,726	.07	.08
October	33	29	32	1,968	.08	.09
November	3,200	33	139	8,271	.35	.39
December	33	33	33	2,029	.08	.09
The year	3,200	25	45	32,204	.11	1.49
1901.						
January	4,180	50	183	11,252	.46	.53
February	4,820	50	925	51,372	2.31	2.41
March	660	50	178	10,945	.45	.52

Estimated monthly discharge of Mohave River at Victorville, Cal.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	44	44	44	2,618	.11	.12
May	49	49	49	3,013	.12	.14
June	42	42	42	2,499	.11	.12
July	40	40	40	2,460	.10	.12
August	50	50	50	3,074	.13	.15
September	55	55	55	3,273	.14	.15
October	69	69	69	4,243	.17	.20
November	77	77	77	4,582	.19	.21
December	73	73	73	4,489	.18	.21
The year	4,820	40	149	103,820	.37	4.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 160.

SAN GABRIEL RIVER.

Estimated monthly discharge of San Gabriel River and canals above Azusa. C[illegible]

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	89	22	32	1,968	0.14	0.16
February	23	18	20	1,111	.09	.09
March	30	16	20	1,230	.09	.10
April	26	13	17	1,012	.08	.09
May	86	16	37	2,275	.17	.20
June	22	8	15	893	.07	.08
July	10	4	6	369	.03	[illegible]
August	5	4	4	246	.02	.02
September	6	3	4	238	.02	.02
October	6	4	5	307	.02	.02
November	.....	.....	[a] 186	11,068	.84	.94
December	.....	.....	[a] 40	1,269	.18	[illegible]
The year	.....	.....	[a] 32	21,986	.15	1.[illegible]

[a] Approximate.

IRRIGATING A FIELD OF SUGAR BEETS IN PECOS VALLEY, NEW MEXICO.

Estimated monthly discharge of San Gabriel River and canals near Azusa, Cal.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,450	28	169	10,391	0.76	0.87
February	2,605	137	680	37,765	3.06	3.19
March	440	135	221	13,589	1.00	1.15
April	130	95	110	6,545	.50	.56
May	272	83	121	7,440	.55	.63
June	93	41	63	3,749	.28	.31
July	41	24	30	1,845	.14	.16
August	27	15	20	1,240	.09	.10
September	20	15	17	1,012	.08	.09
October	122	0	24	1,476	.11	.13
November	50	29	32	1,904	.14	.16
December	30	26	27	1,660	.12	.14
The year	2,605	0	126	88,606	.57	7.49

NOTE.—Gage heights of San Gabriel River for 1901 are given in Water-Supply Paper No. 66, page 161; daily discharge of canals on page 162 of same paper.

LYTLE CREEK.

Estimated monthly discharge of Lytle Creek at head gates Rialto canals, California.

[Drainage area, 52 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	21.7	12.1	15.8	971	0.30	0.35
June	15.2	10.5	12.6	750	.24	.27
July 1–23			10.0	456	.19	.16
August	11.3	9.7	10.4	639	.20	.23
September	11.5	8.7	9.8	583	.19	.21
October 1–25 and 29–31			12.7	705	.24	.25

SANTA ANA RIVER.

Estimated monthly discharge of Santa Ana River and canals near Warm-springs, Cal.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	600	31	78	4,796	0.41	0.47
February	540	48	194	10,774	1.03	1.07
March	114	45	68	4,181	.36	.41
April	107	39	43	2,559	.23	.26
May	68	35	42	2,582	.22	.25
June	44	30	37	2,202	.20	.22
July	42	34	38	2,337	.20	.23
August	200	31	50	3,074	.27	.31
September	60	42	49	2,916	.26	.29
October	96	24	48	2,951	.26	.30
November	36	22	26	1,547	.14	.16
December	25	21	24	1,476	.13	.15
The year	600	21	58	41,395	.31	4.12

NOTE.—Daily discharge of river and canals for 1901 is given in Water-Supply Paper No. 66, pages 164–165.

MILL CREEK.

Estimated monthly discharge of Mill Creek canals at Crafton head works, California.

[Drainage area, 47 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
July	19.12	13.94	15.86	975	0.34	0.39
August			[a] 19.07	867	.41	[a] .35
September	16.58	11.42	14.04	833	.30	.33
October	13.18	12.30	12.58	774	.27	.31
November	12.30	11.60	12.28	732	.26	.29
December	12.28	10.26	12.00	738	.26	.30

[a] Partial month.

NOTE.—Daily discharge in second-feet for 1901 is given in Water-Supply Paper No. 66, page 166.

RELATION OF RAINFALL TO RUN-OFF IN CALIFORNIA.

A study of the available rainfall and run-off data for California watersheds has been undertaken, and the accompanying diagrams and tables are here presented as the results of the work.

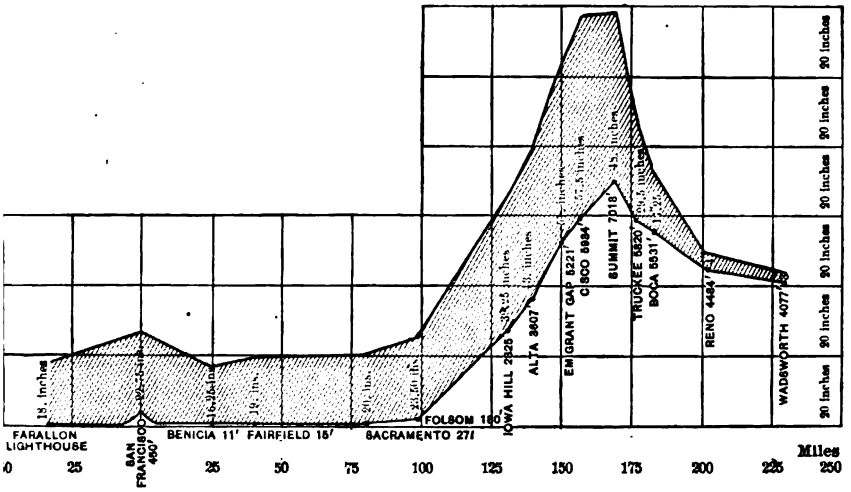

FIG. 70.—Diagram showing increase of rainfall with rise of elevation over the Sierras in central California.

As the run-off diagram was to be used in estimating the water supply available for various storage reservoirs for irrigation, it was thought best to represent the run-off in acre-feet per square mile. The majority of the discharge reports give the depth of run-off in inches. The accompanying table has been made for converting depth of run-off in inches to run-off in acre-feet per square mile, using the following formula: Depth of run-off in inches, x (0.0833 x 640)= run-off in acre-feet per square mile.

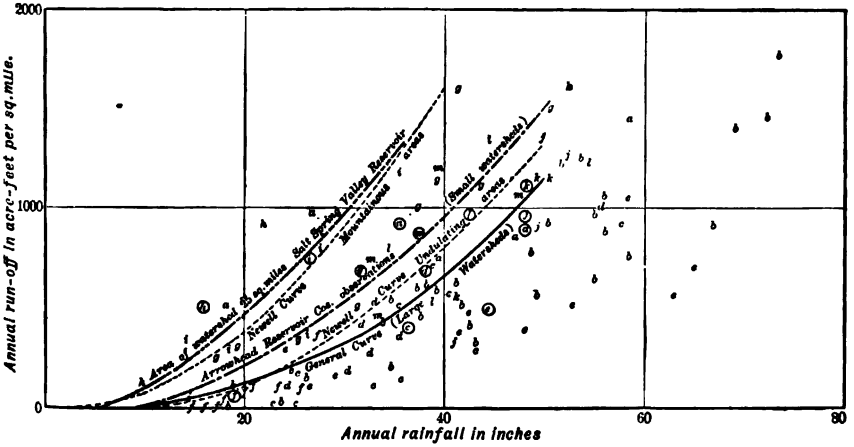

FIG. 71.—Diagram showing run off from watersheds of California streams.

Table for converting depth of run-off in inches into acre-feet per square mile.

Depth of run-off.	Acre-feet per square mile.	Depth of run-off.	Acre-feet per square mile.	Depth of run-off.	Acre-feet per square mile.
Inches.		*Inches.*		*Inches.*	
0.01	0.533	0.35	18.667	0.69	36.800
.02	1.067	.36	19.200	.70	37.333
.03	1.600	.37	19.733	.71	37.867
.04	2.133	.38	20.267	.72	38.400
.05	2.667	.39	20.800	.73	38.933
.06	3.200	.40	21.333	.74	39.467
.07	3.733	.41	21.867	.75	40.000
.08	4.267	.42	22.400	.76	40.533
.09	4.800	.43	22.933	77	41.067
.10	5.333	.44	23.467	.78	41.600
.11	5.867	.45	24.000	.79	42.133
.12	6.400	.46	24.533	.80	42.667
.13	6.933	.47	25.067	.81	43.200
.14	7.467	.48	25.600	.82	43.733
.15	8.000	.49	26.133	.83	44.267
.16	8.533	.50	26.667	.84	44.800
.17	9.067	.51	27.200	.85	45.333
.18	9.600	.52	27.733	.86	45.867
.19	10.133	.53	28.267	.87	46.400
.20	10.667	.54	28.800	.88	46.933
.21	11.200	.55	29.333	.89	47.467
.22	11.733	.56	29.867	.90	48.000
.23	12.267	.57	30.400	.91	48.533
.24	12.800	.58	30.933	.92	49.067
.25	13.333	.59	31.467	.93	49.600
.26	13.867	.60	32.000	.94	50.133
.27	14.400	.61	32.533	.95	50.667
.28	14.933	.62	33.067	.95	51.200
.29	15.467	.63	33.600	.97	51.733
.30	16.000	.64	34.133	.98	52.267
.31	16.533	.65	34.667	.99	52.800
.32	17.067	.66	35.200	1.00	53.333
.33	17.600	.67	35.733		
.34	18.133	.68	36.267		

At the outset many difficulties began to present themselves. The most serious one was that of obtaining measurements of rainfall at the higher elevations. The streams most productive of run-off, and upon which discharge records had been kept, have their sources on the western slopes of the high Sierra Nevada Mountains, where there

are few or no inhabitants above 7,000 feet, and consequently no observers of rainfall, but the valuable rainfall records of the Pacific Railway system along the line of railway from Sacramento to the summit of the Sierra Nevada at Railroad Pass offered a clew to the solution of this difficulty. In fig. 70 the mean rainfall and the elevation of the station are plotted as ordinates and the distance inland of the station as abscissas.

The rate of increase of precipitation from Sacramento to Cisco, at the elevation of 6,000 feet, the point of maximum rainfall, seems to be 0.6 inch per 100 feet of rise. The precipitation above the 6,000-foot point decreases with the elevation approximately at the rate of 0.4 inch per 100 feet of rise.

Fortunately in the Tuolumne River Basin, about midway between the American and King River basins, there is another series of rainfall stations, beginning with Lagrange, elevation 293 feet above sea level; Sonora, elevation 1,824 feet; Second Garrote, elevation 2,900 feet, and Crockers, elevation 4,453 feet. The mean rainfall at these stations, plotted as in the above diagram, indicates the rate of increase from Lagrange to Crockers to be 0.84 inch per 100 feet rise. This rate of increase has been taken to hold good up to an elevation of 6,000 feet, and above this the rate of decrease of rise to be 0.4 inch per 100 feet to an elevation of 9,000 feet. Probably the rate of increase and decrease would be more correctly represented by a curved line, but the data are not sufficient to warrant this.

Using these rates of increase and decrease, the mean precipitation for the years 1896–1899 at an elevation of 9,000 feet in the Tuolumne River Basin would be 49.8 inches. If snow converts into water at the ratio of 8 to 1, the snowfall would be 33.2 feet at this elevation.

It was found impossible to use the run-off data of the Kern River Basin, though it is without doubt the most closely watched stream in the State, because of the exposure of the watershed and because of the scarcity of rainfall data. This watershed is bounded on the west for almost its entire length by a high mountain range. Concerning the precipitation on the east slope of this range there is little known beyond the fact that it is very much less than on the western slope.

In 1896 the total run-off from the King River Basin of 1,775 square miles was 1,871,005 acre-feet. For the same year the run-off from the Kern River Basin was 619,630 acre-feet. The ratio of the area of the King River Basin to the Kern is 1 to 1.32, the ratio of run-off 1 to 0.33, though the higher drainage areas of the streams are contiguous. It was also thought best not to use the run-off and rainfall data for Piru Creek Basin, furnished by the Antelope Valley Water Company, because the ratio of discharge in acre-feet per square mile was greater than any other record. There is little doubt about the accuracy of both the run-off and precipitation records, the explanation being that the rainfall observation stations were necessarily situated at so low an

elevation that the record did not represent the mean rainfall for the higher portions of the basin.

The run-off and rainfall data of the streams which were used to make the discharge diagram, fig. 71, will be mentioned in the order from north to south in which their watersheds occur.

Sacramento River Basin.—The rainfall stations used in determining the mean annual precipitation for the Sacramento River Basin were the following: Red Bluff, Rosewood, Redding, Delta, Dunsmuir, Shasta, Sissons, and Fort Bidwell.

There were absolutely no records for the great interior mountainous and lava country in Siskiyou, Modoc, and Lassen counties, comprising more than 5,334 square miles of the watershed.

Fort Bidwell is situated outside of the watershed, on the eastern slope of the mountains that form the boundary, and would probably have a less rainfall than Modoc County. The record was kept there for a period of twenty-two years, and the mean rainfall is 20.8 inches.

The average rainfall at Red Bluff for a period of twenty-three years was 23.9 inches; at Rosewood, for a period of six years, 25.63; at Redding, for twenty-four years, 35.69. The precipitation at these three latter stations was taken to get the average for the Sacramento Valley for the years 1896–1899, during which time run-off measurements have been made at Jellys Ferry. The mean rainfall of the Pitt River drainage area of 5,334 square miles, which has an average elevation of 5,000 feet, was taken to be the same as that of the Sacramento Basin above Red Bluff.

The average rainfall at Delta for a period of fourteen years was 62.39 inches; at Dunsmuir, for ten years, 57.16 inches; at Shasta, for six years, 53.26 inches; at Sissons, for ten years, 32.75 inches. The rainfall at these four stations was taken to obtain the mean rainfall for the mountainous area of the watershed for the years 1896–1899.

San Mateo Creek.—The Spring Valley Water Company's record of rainfall and run-off from the watershed of San Mateo Creek is without doubt the oldest record in the State, having been kept for thirty years. In the table given on page 390 of Water-Supply and Irrigation Paper No. 38, of the United States Geological Survey, no allowance has been made for evaporation from the surface of the reservoir; 20 per cent has here been added to the run-off as calculated from those tables to cover evaporation. The drainage basin of San Mateo Creek ranges in elevation from 250 to 1,800 feet, with an average of about 750 feet. The hills are undulating. There is a limited growth of timber on the northern slopes near the summit, but a large amount of brush covers other portions of the basin. On the southern slopes and crest the hills are frequently bare of brush, but covered with grasses.

Salt Springs Valley watershed.—The basin of the Salt Springs

Valley is largely of red clay, which scantily covers a bed rock of granite and slate. The topography is undulating rather than mountainous, about 20 per cent of the total drainage area being valley land. There is little brush or timber in the valley and only a scattering growth of oak and scrubby pine on the hills. To obtain the mean for the basin 10 per cent has been added to the rainfall for North Hill, 6 miles northwest of the dam. To obtain the total run-off for the basin 4,132 acre-feet have been added to the amounts as given in the table on page 337, Part IV, of the Eighteenth Annual Report of the United States Geological Survey to compensate for evaporation from the reservoir surface.

The methods of measurement of discharge from the reservoir are very crude, which may partly account for the very high percentage of run-off from this basin, which contains 25 square miles.

Stanislaus River Basin.—There were no rainfall data obtainable for this basin, but, since it joins the Tuolumne and is in most respects similar, the rainfall for the Tuolumne Basin has been taken to apply to both.

Tuolumne River Basin.—To obtain the mean rainfall for this basin the average elevation and area of the various portions were taken from the topographic maps of the United States Geological Survey. The areas were obtained by the use of a planimeter. Lagrange was taken as the base station and the percentage of increase for the various elevations, as shown by the diagram, fig. 1. The following example for the year 1896 will illustrate more particularly the method:

Average elevation.	Number of square miles.	Estimated rainfall, 1896.	Mile-inches.
1,200	75	26.4	1,980
1,500	88	29.0	2,552
2,500	182	37.4	6,807
3,500	46	45.8	2,107
4,000	105	50.0	5,252
4,500	147	54.2	7,967
5,500	90	60.9	5,481
6,000	143	63.3	9,052
6,500	105	61.3	6,437
7,500	189	57.3	10,830
9,000	330	51.3	16,927
.....	1,500	.....	75,692

$\frac{75692}{1500} = 50.3$ inches mean for basin, 1896.

Tabulation of general curve.

Estimated mean rainfall in inches.	Estimated run-off in acre-feet per square mile.	Estimated depth of run-off in inches.	Estimated mean rainfall in inches.	Estimated run-off in acre-feet per square mile.	Estimated depth of run-off in inches.
8	0	.00	30	330	6.20
10	10	.19	32	380	7.13
12	15	.28	34	430	8.06
14	35	.66	36	500	9.38
16	55	1.03	38	580	10.87
18	85	1.60	40	660	12.38
20	120	2.25	42	750	14.06
22	160	3.00	44	840	15.75
24	200	3.75	46	940	17.62
26	240	4.50	48	1,040	19.50
28	280	5.25	50	1,160	21.75

San Joaquin and King River basins.—There were practically no rainfall data for either of these basins.

The estimated mean rainfall for the Tuolumne River Basin for the years 1896–1899 is 48.2 inches; the depth of mean run-off for the same period is 20.8 inches; the depth of mean run-off for the San Joaquin River for this period is 18.4 inches. Since the topography, exposure, etc., in the two basins are similar, the rainfall will probably be proportional to the run-off.

Example: 20.8:18.4::48.2:42.7. Similarly the mean rainfall for the King River Basin will be 37.8 inches.

Mohave River.—The meteorological and hydrographic work of the Arrowhead Water Company has been carried on for a number of years at the head of the Mohave River. Twenty-eight rain gages, carefully located at elevations of from 2,100 to 7,200 feet, have been maintained. The measurements of run-off from several tributaries have been made over weirs. The area of the basins are all less than 50 square miles. The watershed is covered with a thick growth of timber on the crest. The growth of timber diminishes as the desert is approached, the northern part of the watershed being covered with brush only. The mean elevation of the watershed observed upon is about 5,250 feet above sea level.

Cuyamaca reservoir watershed.—The area of this watershed is 11 square miles and the mean elevation above sea level is probably 5,500 feet.

The run-off is carefully measured. There is only one rain gage maintained, and that is at the dam. The resident engineer, Mr. F. S. Hyde, says that as this rain gage is located between two high wooded

peaks, which act as condensers of the moisture-laden clouds, the recorded precipitation is undoubtedly heavier than the average of the watershed. This probably explains why the mean annual run-off is so far below the general curve.

Sweetwater reservoir basin.—The evaporation and run-off records from this basin date from 1888, and have been very carefully kept.

There is no doubt that many of the points on the curves (fig. 71), would be changed if we had more definite information as to the rainfall, but the curves are the best that could be made from the information at hand. The mean discharge for the period of observation on each stream is used, together with the mean rainfall for the same years. These means are considered the more satisfactory, as they tend to eliminate erratic stream and rainfall records.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

OBSERVATIONS ON THE FLOW OF RIVERS

IN THE

VICINITY OF NEW YORK CITY

BY

HENRY ALBERT PRESSEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 23, 1902.

SIR: I transmit herewith manuscript for Water-Supply and Irrigation Paper No. 76, by H. A. Pressey, entitled Observations on the Flow of Rivers in the Vicinity of New York City.

Respectfully,

F. H. NEWELL,
Hydrographer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

OBSERVATIONS ON THE FLOW OF RIVERS IN THE VICINITY OF NEW YORK CITY.

By H. A. PRESSEY.

INTRODUCTION.

One of the chief resources of the United States is its water supply. The prominent industrial position of several States is due largely to the abundance of their available water. It has recently been stated that "the preeminent position of the State of New York is due almost entirely to her great natural resources;" that "her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth," and that "the history of the State's progress during the nineteenth century is largely a history of the development of her water resources." These remarks apply quite as aptly to some of the New England States, as they could not have held the front rank in the industrial world for so many years were it not for the very extensive utilization of the magnificent waterfalls of that region. In the Southern Atlantic States the great developments during the last few years are due largely to the development and utilization of water powers.

There is not a State along the Atlantic coast, except Delaware, that does not contain water powers, developed and undeveloped, and, contrary to the opinion of many, there never was a decade in the history of our country when the development of water power made such strides as during the last ten years. According to the returns of the Twelfth United States Census the increase in the utilization of water power in the United States in the ten years from 1890 to 1900 was about 30 per cent, or 472,361 horsepower. In some States this increase was remarkable, as, for instance, in Maine, where in the last decade the developed power increased 60 per cent.

The importance of our water powers as a source of wealth can hardly be overestimated. This power is not confined, however, to the Eastern States, for in the great Central Northwest, on the Pacific slope, and elsewhere there are water powers of great size and value, many of which form the basis of the industrial life of large communities. In the broad, flat plains of the United States west of the Mississippi

the rivers are valuable from another standpoint. In this region the streams commonly lack the fall required for power development, but here the water supply is, perhaps, more vital to the life of the region than in the coastal States. Great areas of land depend for water largely upon the rivers in their vicinity and upon artificial means for raising and distributing it over their soils. Without water there can be no life in this region; with water, vast areas can be reclaimed as agricultural land of great fertility.

In most parts of the country the public water supply of the cities and towns must be derived from the rivers. Large sums are expended every year in conducting water from the streams to the centers of population. Before this money is expended it is of the greatest importance to know that there is sufficient water at all times for the use of the town. Too often have great hydraulic works been built before proper investigation has been made of the flow of a stream, and great financial loss has resulted.

It is to furnish information upon which to base estimates of available water supply that the Hydrographic Division of the United States Geological Survey has been, during the last fourteen years, collecting data in regard to the flow of rivers in the United States, and their variation from season to season and throughout a series of years. The necessity for such data is frequently brought to the attention of the engineer, sometimes in a most startling manner. The lack of this information frequently leads to the most disastrous mistakes in the construction of hydraulic works. One of the best examples of this in the design of a hydraulic plant was the construction of a dam and water-power plant at Austin, Tex. After an expenditure of $1,600,000 it was found that a grave mistake had been made in the estimate of the low-water flow. The works were constructed by the city in accordance with a vote of the citizens of Austin in 1890. It was estimated that 14,000 horsepower could be developed, and the people felt that their city was to become a great manufacturing center. No hydrographic data had been collected, except from the hazy memory of the "oldest inhabitant." In the spring of 1890 a measurement of flow giving 1,000 cubic feet per second was taken as the minimum. This estimate was more than five times too great, as was shown by subsequent measurements. An error of 500 per cent had been made in the estimate, but this was not ascertained until the works were nearly completed.

Mistakes of this kind have occurred in every part of the country in hydraulic works. The Sweetwater dam in California in a good example of a project carried through on insufficient data. The dam was built after a series of wet years and was soon after filled to overflowing, so that increased spillways were constructed, but since that time the water in the reservoir has never reached an elevation near the crest of the spillways, and during most of the time there has been the greatest scarcity of water.

The Bear Valley dam is a more marked case, as the reservoir formed by the dam has been practically dry for several years, so that wells have been driven in the bottom of it.

The Gila Bend, Arizona, project is another example of the expenditure of a large sum—$900,000—upon insufficient data, and subsequent abandonment of the scheme. In this project the dam was carried away before its completion, but had it been completed the scheme must have proved a financial failure.

Many diversion canal projects for irrigation have been either partial or complete failures on account of shortage of water; that is, developments have been made far beyond the capacity of the stream.

A great number of water-power plants have been constructed upon insufficient data, and later, auxiliary steam has been found necessary. Allowance was not made in the original estimates, so that in a number of instances the project has been found unprofitable. Knowl- of the flood flow is also of great importance in designing the dams and waste ways.

Frequently the cause of such errors is a complete ignorance of the hydrographic conditions in the drainage basin of the stream and often of the region in which the stream is located. In a few cases no adequate efforts have been made to obtain information; perhaps a single measurement may have been made at a time when a local resident informed the investigator that the "river is now as low as it ever gets." In order to test the accuracy of such methods, the writer has often asked old inhabitants on the banks of the river as to the variation in the river height, and has been informed that "it is now at its lowest stage;" or, that "it never falls more than 2 or 3 inches below its present height." At a later visit to the stream in the same season the river surface has been found to be at an elevation 2 or 3 feet below its previous stage. The word of the oldest inhabitant is sometimes fairly reliable as to high water, but his information as to low-water stages should be carefully checked, and the fact that a number of the inhabitants say that the river never goes lower is not sufficient evidence upon which to construct hydraulic works.

Rainfall data are often used in discussing the variation of flow of a stream, and numerous theories and formulas are applied to show that the flow can never fall below a certain amount, these theories to be sadly shaken later, when measurements are made and the facts ascertained. In a few cases greater weight has been given to these theories than to actual measurements, even though the measurements were made by a careful and reliable engineer. The measurements were lower, perhaps, than theory would suggest, and therefore the measurements must be wrong.

In studying the flow of a stream every possible source of information should be utilized—even the ideas of the oldest inhabitants—but to most engineers it is very reassuring to know that actual measure-

ments of the discharge have been made and are available for use. If measurements of the stream under consideration have not been made, then results obtained from measurements of rivers in the immediate vicinity can be used to advantage, care being taken that the hydrographic, topographic, geologic, and forest conditions in the two basins are similar.

As an example of the difficulties under which a prospective investor labors, there are now before the writer reports upon a certain stream in New York State made by five different engineers, all of good standing, in which estimates of the minimum flow of the stream under consideration vary from 0.20 to 0.40 cubic foot per second per square mile; that is, the minimum flow given by one engineer is just twice that given by another. As the development of a water power is limited largely by the low-water flow, the uncertainties arising from such divergent opinions are apparent. Since these reports were made (1900–1901) the flow of this stream has been measured, and the lowest estimate made by the engineers has been shown to be at least 100 per cent too great. In estimates of this kind facts are needed—that is, actual measurements of discharge.

No further discussion is probably necessary to convince most thinking people that the measurement of the larger streams of the United States is an important undertaking, and that capital will be invested in power developments, irrigation, sanitary and other hydraulic works more freely when information as to the flow of the streams is available.

In making measurements of streams it is of course desirable that rapid and economical methods be used, if such are of sufficient accuracy. Methods of stream measurements have been discussed in Water-Supply Paper No. 56, and it is not the purpose of this paper to deal with that question extensively, but rather to point out certain facts developed, during the last few months, by measurements of streams in the southern part of New York State, with the idea that some of the data obtained from these measurements may be useful in studying the flow of other streams and may assist in the selection of methods that will expedite the work and yet give results sufficiently accurate for all practical purposes.

In considering the future demands of the city of New York for water several additional sources of supply have been suggested: Housatonic River, Tenmile River, Wallkill River, Rondout Creek, Esopus Creek, and Catskill Creek, the Hudson River or some of its upper tributaries, Lake George, Lake Champlain, and the Great Lakes. The three last-named sources have been discussed in print somewhat extensively[a] and will not be taken up here. It has been found that the supply from Lake George would not be adequate; that Lake

[a] Report of Merchants' Association of New York on the water supply of the city of New York, August, 1900.

Champlain is at too low an elevation for economical use, and that the supply from the Great Lakes would entail great and unnecessary expense. The water from the Hudson River might be taken near its headwaters and conducted to New York City by a long aqueduct, or the intake might be located just above Poughkeepsie, in which case the water would have to be pumped from the river and filtered before delivery to the city. In either case it is important to know the discharge of the Hudson at various seasons of the year to determine the quantity available and also the effect of the diversion of water upon the regimen of the river.

The United States Geological Survey has for several years been measuring the daily flow of streams throughout the United States, the results of these measurements being used for different purposes, including irrigation, water-power, and sanitary constructions.

Measurements of flow of Schroon River at Warrensburg and of the Hudson at Fort Edward and Mechanicville have been made, also of the Mohawk and its chief tributaries at various points, and the results of these have been published in the annual reports.

The measurements of the rivers discussed in this paper were started at the suggestion of Mr. George N. Birdsall, chief engineer Bureau of Water Supply, New York City, in order that data might be available for investigations as to additional water supply for New York City. The following stations were established by the United States Geological Survey during the summer of 1901 and have been maintained continuously since that time.

Gaging stations on rivers near New York City.

Stream.	Location of gaging station.	Drainage area—		
		Above proposed reservoir.	Above gaging station.	Above mouth.
		Sq. miles.	*Sq. miles.*	*Sq. miles.*
Tenmile River	Dover Plains, N. Y	200	195	195
Housatonic River	Gaylordsville, Conn	1,020	1,020	1,580
Catskill Creek	South Cairo, N. Y	140	260	394
Esopus Creek	Kingston, N. Y	242	312	417
Wallkill River	New Paltz, N. Y	464	735	779
Rondout Creek	Rosendale, N. Y	184	365	[a]369
Fishkill Creek	Glenham, N. Y	158	198	204

[a] Above junction with Wallkill River.

A reconnaissance of each of these streams was made, and stations were selected at points where measurements could be most accurately made, and as far as practicable at points where it was thought knowledge of the flow would be most desired in the future study of these

watersheds as sources of increased supply for New York. The results of the observations at these stations have been published in the Water-Supply Papers of the Survey. The height of the water at each station has been noted twice each day by a local observer and current-meter measurements have been made at frequent intervals by a hydrographer. From these meter measurements a rating curve has been drawn for each station which shows the relation between the height of the water in the river and the discharge. From this curve and the daily mean gage height the flow of the river for each day in the year since the establishment of the station can be determined. These data will be of the greatest importance to the engineers selecting the source of supply, as they furnish the first continuous record of the flow of these streams and give a basis upon which to compute the supply available from each stream, which, with the topographic maps of the survey and the detailed surveys of the reservoir sites, will give complete data for the estimate of the quantity of water that can be furnished by each of these drainage basins and of the relative cost per million gallons of the supply from each.

In addition to the measurement of the discharge, determinations of turbidity, color, alkalinity, and hardness have been made upon each of these streams and are now being continued, and it is thought that these data will prove valuable in the final selection of the new source of supply. Results are given in the Water-Supply Papers of the United States Geological Survey, and are tabulated at the end of this paper.

In making gagings at these stations it was thought desirable to investigate the variations of flow in different parts of the river channel, in order to determine at what points the velocity could be measured to ascertain the mean velocity in the channel without unnecessary expense or loss of time. Before taking up the measurements and the vertical velocity curves constructed, it may not be out of place to describe briefly some of the methods used for the measurement of streams.

METHODS OF MEASURING VELOCITY IN RIVER CHANNELS.

There are in common use a number of methods of measuring the flow of rivers. In general these involve the determination of the mean velocity of the current and the area of the cross section of the stream. The latter is easily computed from soundings made at frequent intervals across the channel. These soundings must be taken at intervals so short that the bottom of the river may be considered a straight line between soundings. Usually the velocity of the current is determined in sections of the river channel, these sections extending between the points of soundings. The summation of the area of each of these sections gives the total area of the cross section. When the

total flow of the river is known and is divided by the area of the cross section the result is called the mean velocity of the river. It is this mean velocity that we try to determine in any method of stream measurement, but, as a matter of fact, it can not be actually determined until the total flow is known.

In the determination of the mean velocity of the current there are a number of methods giving results more or less accurate, all of which should be familiar to the engineer, so that the method best suited to the conditions at hand may be applied.

FLOATS.

GENERAL METHODS.

Floats are frequently employed to determine the velocity of the current. There are three general types in common use: First, surface floats; second, subsurface or double floats; third, tube or rod floats. The general method of procedure is the same whichever form of float is used. The site for making a float measurement should be on a straight reach, having a fairly uniform cross section. The flow of the water should be regular, without sudden rapids or stretches of still water, and should exhibit no tendencies to form eddies or cross currents caused by irregularities in the channel or resulting from the effect of a sharp bend above the reach. The course of the floats should have a length of from 100 to 300 feet, and the areas of cross section at the upper and lower ends of this course should be carefully determined by soundings. When courses more than 100 feet in length are selected, it is desirable that additional cross sections, at equal intervals from one another, should be measured. As a preliminary step, a base line should be laid out by tape on the bank as nearly as possible parallel with the stream, and points should be marked opposite the cross sections to be used. If the stream is not too wide the soundings in the cross sections can be taken most conveniently along a tagged rope stretched across the channel at right angles to the base. If the depth does not exceed 4 feet this can be done by wading, the depth being read on a rod graduated to feet and tenths. Should the depth of the channel or the temperature of the water make wading impossible, a boat may be used. On large rivers, where a tagged rope can not be employed, the boat from which the soundings are to be made should be located by simple triangulation. Soundings should be read to tenths of a foot and be taken preferably at equal distances apart. In deep rivers a tagged rope or chain with lead weight can be substituted for the rod.

SURFACE FLOATS.

In reconnaissance work, in which the equipment is as a rule limited by transportation facilities, surface floats consisting of chips will be found most convenient. The use of rod floats, though giving more

directly the mean velocity, has many disadvantages, and should not be attempted unless the time and opportunity permit of obtaining floats of the required lengths. In the simplest case but one man is needed to make the observations. The surface floats should be thrown into the stream a considerable distance above the first cross section. The hydrographer should attempt to start the floats, successively, at different distances from the shore in order to determine the velocity in different parts of the channel. The time of the passage of each float between the upper and lower cross section should be noted, preferably by a stop watch, and also the position of each float with respect to the tags on the ropes. This will enable the hydrographer to determine whether or not he succeeds in covering the different parts of the stream, and it will serve as an aid in the computation. The observations should be continued until all parts of the stream have been covered.

On wide rivers range poles may be established on opposite shores to mark the upper and lower cross sections. The location of each float as it crosses these imaginary lines can readily be recorded by triangulation. A light traverse plane table will be found especially useful in obtaining a graphic record.

The surface floats show approximately the surface velocity of the stream at the point of measurement. The results obtained by this method are subject to errors due to wind and surface currents and eddies. The velocity shown is that of the surface of the river, while that required for computation of discharge is the mean velocity of the cross section. Unfortunately, the relation of the surface to the mean velocity of the vertical is not constant, yet for streams of the same general character of bed, banks, velocity, etc., the ratio is sufficiently constant to allow the mean velocity to be computed with fair precision from the surface velocity observations.

SUBSURFACE OR DOUBLE FLOATS.

The double float consists of a small surface float connected by a fine cord to a larger subsurface float, which is so arranged that it shall always remain at the point of mean velocity in the current. The surface float may consist of a flat block of wood or a tin water-tight drum, which floats upon the surface of the water with sufficient buoyancy to prevent the larger subsurface float from sinking. The subsurface float may consist of two sheets of galvanized iron set at right angles, weighted at the bottom, with an air-tight cylindrical device at the top, in order that it may at all times keep its vertical position. A round, hollow cylinder of tin also makes an excellent subsurface float. The tension on the connecting cord should be at least 2 or 3 pounds, and the cord should be of silk and as fine as possible in order that its resistance to the current should not have a marked effect upon the velocity of the floats. The length of the cord

should be so regulated that the lower float may be at the point of mean velocity, and the resistance of the upper float and the cord should be made as small as practicable. A small flag should be placed upon the upper float in order that its position may be easily determined at all times. The chief objection to double floats is the uncertainty as to whether the cord is vertical and the consequent uncertainty as to the position of the subsurface float. Another objection is the modifying effect of the surface float and the cord upon the velocity of the lower float, as in great depth the exposed surface of the cord may exceed that of the float. A third objection is the uncertainty as to the vertical position of the lower float, as, owing to changes in depth of water and local conditions, the point of mean velocity may change, whereas the length of the connecting cord must remain constant in each run. This may introduce a noticeable error if the increase in depth is large, as the retarding effect of the slow velocity near the bottom of the river will not be felt by the float, and the result will show too high a velocity. The lower float may tip slightly, owing to eddies or other causes, thereby changing the exposed surface, or, unknown to the observer, the lower float may strike a bowlder, causing its velocity to be checked. In many cases these objections would not be at all serious, but, in general, when floats are to be used better results can be obtained, when the depth is not too great, by the use of rod or tube floats.

ROD OR TUBE FLOATS.

These consist of long, cylindrical tin tubes or wooden poles, 2 or 3 inches in diameter, weighted at the bottom, so that they will float vertically with only 2 or 3 inches exposed above the water surface. These rods integrate the velocities in a vertical section and give approximately the mean velocity of the current. It is important that they should extend nearly to the bottom, as otherwise the velocity, as shown, will be too great, yet the greatest care must be taken that they do not at any time scrape upon the rocks at the bottom or sides so as to retard their movement. Rod floats are free from many of the objections to double floats, as there is no uncertainty as to their position nor as to the point of mean velocity in the channel. They are not, however, suitable for very deep rivers, or for channels where the depth varies considerably, or where weeds grow in the bed of the stream. Mr. James B. Francis has stated that the rod floats travel a little faster than the mean velocity of the water even for the depth of immersion. The float will be subject to pressures proportional to the square of the relative velocities of the water at different points, and when it has attained its full speed there will be equilibrium between these different pressures. This equilibrium may exist, however, when the speed of the float is somewhat different from the mean velocity of the water, the latter being the arithmetical mean of all the different

velocities throughout the depth of immersion. The following formula for correcting an observed velocity was derived by James B. Francis from his Lowell experiments:

$$V_m = V_o\left[1 - .116\left(\sqrt{\frac{d-d'}{d}} - 0.1\right)\right]$$

Where V_m is equal to true mean velocity in vertical, V_o equals observed velocity of tube, d equals mean depth along path of tube, d^1 equals depth of immersion of tube.

Col. Allan Cunningham[a] has, however, calculated that such floats move somewhat slower than the water in which they are immersed. The error of assuming that the velocity of the tube represents the mean velocity in the vertical will not be material unless tubes too short are used, in which case the velocity as shown by the tube should be somewhat reduced.

WEIRS.

By the method of weirs the discharge of the stream is computed by means of an empirical formula, which varies for different types of dams or weirs. On creeks or small rivers it is sometimes practicable to build a timber weir across the channel, causing the total flow of the stream to pass over the sharp edge of the weir crest. By observing the head on the weir, computations of the flow can be made. This is probably the most accurate method applicable to small streams. On large rivers, however, the cost of a weir is usually so great as to be prohibitive, so that if there is not a weir or dam already in the stream it is necessary to resort to measurements by floats or current meters.

On many of the rivers of moderate size the conditions are unfavorable for successfully applying either of these methods. For instance, on streams used for manufacturing purposes dams occur at frequent intervals, interrupting the regular flow, and in many cases holding back the night flow for use during the following day, so that the discharge during the night may be either nothing or a very small percentage of the day flow. Then, too, the shutting down of the mill wheels for an hour at noon may have a pronounced effect upon the results of float or meter measurements made below the mill. Unfortunately these variations are not always apparent to the hydrographer, and surprise and annoyance are caused by finding that the river height differs by several tenths from the gage as read by the regular observer a short time before the hydrographer arrived at the station.

Under the conditions described, better results can undoubtedly be obtained if there exists upon the stream a good dam which can be used as a weir. It should have a level, even crest and a constant cross section, with sufficient pondage to reduce the velocity of approach, and it should be free from leakage. Masonry dams are better for

[a] Recent hydraulic experiments: Min. Proc. Inst. Civil Eng., Vol. LXXI 1883.

A. CURRENT METER IN USE, SUSPENDED FROM A BRIDGE.

B. CABLE AND CAR USED TO MEASURE DISCHARGE OF RIVER

this purpose, for they are more likely to be tight and to have an even crest. Timber dams, although level when first constructed, are likely to settle at various points, thus producing an uneven crest elevation. There are, however, many good timber dams practically free from leakage and with crests sufficiently uniform for accurate work.

Having selected a dam as the proper site for a station, a careful survey must be made of the crest line and of the upper and lower slopes, so that it can be compared with other dams or with experimental sections for which the coefficients of flow are known. The experiments of James B. Francis, of Fteley and Stearns, and of John R. Freeman, George W. Rafter, and others at Cornell University, have given coefficients upon many sections of various forms. It is probable that the dam selected for the station will not be exactly like any of the experimental forms, but it will resemble some of them so closely that coefficients can be selected for the computations.

When the mill gates are open a part of the flow is diverted from the river through the mill race, the gates, and the tailrace.

The amount of the diversion must of course be measured and added to the quantity flowing over the dam, in order to determine the total discharge of the stream. In many factories the quantity flowing through the wheels varies from day to day, and also during different hours of the day, so that careful records must be kept of gate openings, in order that proper allowance may be made for these variations. The size and the make of the water wheels must be ascertained, and the wheels be used as water meters for the determination of the flow through them. Many of the modern wheels have been carefully rated. Where such ratings have not been made, usually records of wheels of the same type, though possibly of different makes, can be found and the records be compared. Water wheels as meters give fairly accurate records of the discharge.

The Chezy formula or surface-slope method has been extensively employed in gaging large rivers. The proper coefficients to be applied are usually determined from the auxiliary formula of Gauguillet and Kutter. One difficulty in the application of this method lies in the selection of suitable friction factor or coefficient of roughness.

CURRENT METERS.

The current meter has been found best adapted to the general measurements made by the United States Geological Survey, and is used almost exclusively in its hydrographic investigations. (Pls. I and II.) Occasionally, however, either a meter is not available or the conditions are not favorable for its use. In such cases weirs or floats have been used, though a Pitot's tube, hydrometric pendulum, or hydrometric balance might in exceptional case be used to advantage.

The current meter has been described, and instructions for the care and use of the instrument have been given in Water-Supply Paper

No. 56. The object of the present discussion is to give a few additional facts as to the point at which the meter should be held to determine the mean velocity in a channel, as deduced from measurements recently made upon rivers in the southern part of New York State. The current meter may be used to determine the velocity of a river in four ways: First, by making point measurements at a depth corresponding to the approximate position of the thread of mean velocity; second, by deducing the mean velocity from observations made at other points in the same vertical; third, by the integration method; fourth, by point measurements made at regular intervals throughout cross sections of the river. In the first two of these methods it is important to know the relation between the velocities at various points in the section. In the first method the position of mean velocity must be known, and in the second method the relation between the surface velocity, or the velocity at mean depth, to the mean velocity must be known. In either of these cases the form of the vertical velocity curve will determine the coefficient to be applied to the observations.

VERTICAL VELOCITY CURVES ON STREAMS WITHOUT ICE COVER.

Studies of the vertical velocity curve made on the Mississippi River by Humphreys and Abbott, on the Connecticut by T. G. Ellis, on the Merrimac flume by Wheeler and Lynch, on the Potomac by C. C. Babb, and recent experiments by others, notably those at Cornell University by E. C. Murphy, indicate that the point of mean velocity in a given vertical section is at a depth varying from six-tenths to two-thirds of the total depth of the section, measured from the surface down. The values found in the experiments were as follows:

Depth from surface of point of mean velocity.

Experimenter.	Stream.	Depths.
Cyrus C. Babb	Potomac River	0.58
Humphreys and Abbott	Mississippi River	.63
T. G. Ellis	Connecticut River	.64
E. C. Murphy	Cornell flume	[a].65
Wheeler and Lynch	Merrimac flume	.67

[a] For depths between 6 and 9 feet, the proportionate depth of point of mean velocity becoming less as the depth of the water decreased, and becoming 0.55 for depths of water between 1 and 2 feet.

The Cornell experiments indicate that measurements made at six-tenths of the depth yield results 3.5 per cent too large, the depth of

PRICE ELECTRIC CURRENT METERS.

mean velocity being nearly two-thirds of the depth. The measurements at Cornell were, however, made in the canal, the cross sections of which have a greater ratio of depth to width than most rivers, and decidedly more than the Mississippi, Connecticut, and Potomac, upon which the above coefficients were obtained. There can be no doubt but that the difference in the ratio of the depth to width is a factor likely to affect the position of mean velocity.

The bottom and sides of the channel retard the flow close to them in proportion to their roughness, this retardation being due more to the impeding of the flow by eddies than by friction alone. The retardation of the surface velocity has been attributed to the rising, by vertical motion, of the lower water to the surface after being checked in its flow by striking against the rough bottom and sides of the channel. The variation of the velocity in the river channel is shown in Pl. VIII (p. 30) and fig. 1.

Mr. Frederick P. Stearns has attributed the reduction of surface velocity to the general retarding of the layers of water adjacent to the banks of the stream, this water rising to the surface and thereby making the edges of the channel higher than the center and causing a flow of the slowly moving water from the sides toward the middle, thereby decreasing the surface velocity, depressing the point of maximum velocity, and lowering in general the filament of mean velocity. This depression of the maximum velocity is known to become more pronounced with an increase in the roughness of the lining, in the steepness of the banks, and in the ratio of depth to width. In an extreme case of a wide, shallow stream, where the bottom merges imperceptibly into the banks, maximum velocity occurs, under normal conditions, at or very near the surface of the center of the stream. On the other hand, in a deep, narrow channel, as for instance, in a canal with vertical sides, the maximum velocity occurs a considerable distance below the surface, and, as the Cornell experiments indicate, this depression may amount to as much as one-third and even two-fifths of the total depth. Evidently, then, in such cases depression of maximum velocity must result in a lowering of the thread of mean velocity, and engineers, in making unit measurements for mean velocity, should bear in mind that while the observations at six-tenths depth give fair values for mean velocity in wide, shallow rivers this ratio should be increased to two-thirds in the case of canals and flumes or narrow natural channels.

The friction of flowing water against the air has a similar influence, and, though in general less marked, it may, in the case of a strong upstream wind, have a decided influence upon the surface velocity and the point in the vertical of the maximum and mean velocity. On account of these resistances on the bed and bank of a stream, the maximum velocity of the river in a straight reach is found in the cen-

tral portion of the stream, and somewhat below the surface—the actual position depending upon the size and condition of the river and the velocity of flow. The velocity increases from the surface downward for a short distance—say, one-tenth of the depth—and then decreases down to the bottom, where it reaches the minimum.

Various writers who have studied the form and equation of the curve representing the variation in velocities in a vertical section have

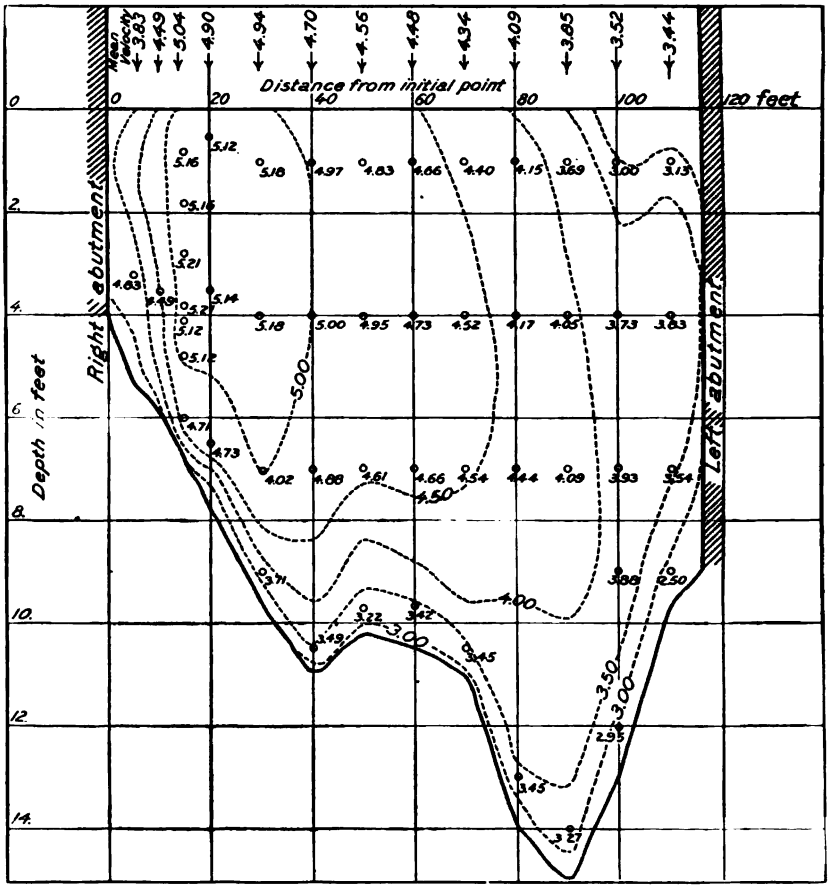

FIG. 1.—Cross section on Esopus Creek, at Kingston, showing curves of equal velocity as determined by current-meter measurements, there being no ice cover.

come to different conclusions as to the form of this curve, the inclined straight line, the parabola with horizontal axis, the parabola with vertical axis and vertex at or below the surface, the ellipse, and the hyperbola each having its advocates. Humphreys and Abbott showed by their experiments on the Mississippi River that the curve did not differ materially from a parabola having its axis parallel to the surface and at the depth below the surface of the position of maximum veloc-

ity, the abscissas representing the velocities at the different depths and the ordinates the vertical distances of these depths from the point of mean maximum velocity. In the Mississippi River experiments the position of maximum velocity was on an average nearly one-third of the whole depth below the surface, varying with the direction of the wind. Bazin also found that the vertical velocity curve was in the form of a parabola, the curve varying with different channels and the position of maximum velocity. Professor von Wagner agreed with the above experimenters, but found that the curve differed from the parabola toward the bottom and near the surface, and that the point of maximum velocity varied from a little below the surface to a little over one-fourth of the full depth.

The exact mathematical form of a vertical velocity curve is not a vital question in the measurement of streams, but it is greatly to be desired that the relation between the surface, maximum, and mean velocities should be known, so that if any one of these be measured accurate computations of the flow can be made, and so that if the velocity of the stream be measured at some particular point the mean velocity of the whole section can be calculated. It has been shown by a series of measurements, the results of which are given herein, that the typical vertical velocity curve is in general of the form shown in fig. 2; that the surface velocity is somewhat greater than the mean; that the maximum velocity is below the surface but above mid depth; and that the point of mean velocity is from 0.6 to two-thirds of the depth below the surface. The relation between the surface velocity and the mean velocity is, of course, important in the use of surface floats and current meters when the velocity is measured only near the surface, for some coefficient must always be applied to obtain the mean velocity in the vertical section. In this connection, some results obtained by Mr. J. B. Lippincott on rivers in southern California, in April, 1902, are of interest:

On the Sacramento River, at Jellys Ferry, observations for velocities have been taken at the top, middle, and bottom of each section at intervals of 20 feet. The channel is of bowlders and has a depth of from 3 to 5 feet in the low-water stages. The relation of the mean velocity to the top velocity on each section was determined, and then the mean ratio for the entire measurement. The measurements were arranged in 6 groups according to gage heights. In the first group the mean velocity was 87 per cent of the surface velocity; in the second 88; in the third 88; in the fourth 89; in the fifth 87; in the sixth 87. The last group represents the highest water. The mean of 30 measurements gives a ratio of 88 per cent. In this case the coefficients are quite constant.

A determination on the Tuolumne River, at Lagrange, also gives a coefficient of 88 per cent. This river has a pebbly or stony bed, and the depths range from 1.12 to 1.84 feet. The velocities range from 3 to 5 feet.

On the smaller rivers the determinations were less satisfactory, because when depths become as low as 1 foot, top, middle, and bottom velocities were seldom observed with meters, and unless we had three observations for velocity the mean

velocity was not considered sufficiently accurate to justify a comparison with the surface velocity.

The relative irregularities of the beds of the smaller streams also introduced wider ranges in the relation of surface to mean velocities.

On the San Gabriel River the following results were obtained at different points on the stream: 0.88, 0.94, 0.95, 0.89, 0.90, 0.98; mean, 0.92.

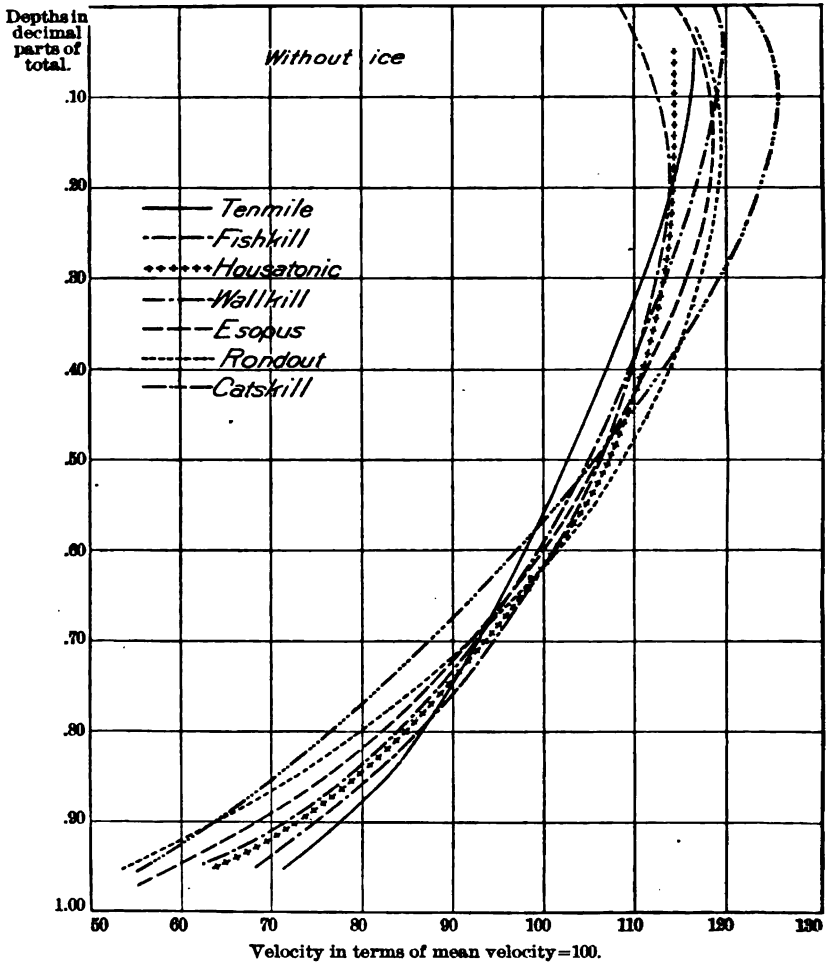

FIG. 2.—Mean vertical velocity curves for Esopus, Rondout, Catskill, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers.

On the Santa Ana River the following determinations were made at Warm Springs: 0.96, 0.95, 0.91, 0.86, 0.90, 0.91, 0.96, 0.93; mean, 0.92.

The channels of these two streams are relatively rough, the water surface is usually from 10 to 20 feet in width, and the depths vary from 0.25 foot to 1 foot for the stage of water observed upon. It is rather singular to note that the determination of these coefficients in the smaller and relatively rough channels shows a higher value than in the larger channels. As previously remarked, how-

ever, the determinations for the San Gabriel and the Santa Ana are not considered as entirely satisfactory nor as reliable as the determination for the Sacramento. It is possible that the coefficients which we have determined for the smaller streams are too high, owing to the fact that the current meter could not be placed in the slowest film of water immediately adjacent to the bottom and sides of the channel, so that the mean velocity as shown may be slightly above the true

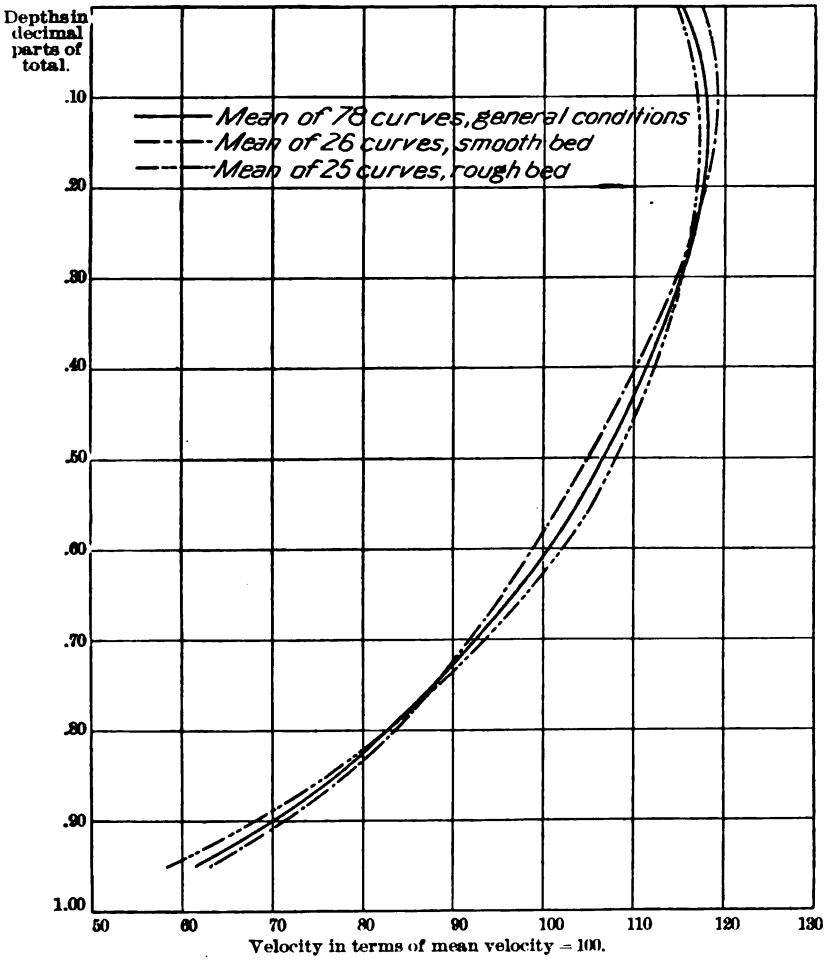

FIG. 3.—Comparison of the general mean velocity curve with the mean curve for smooth bed and the mean curve for rough bed. (Note: The general mean curve includes all data obtained in 78 vertical velocity curves; the mean curve for rough bed includes the data for 25 vertical velocity curves, and the mean curve for smooth bed includes the data for 26 vertical velocity curves. All of these curves were taken when there was no ice cover.)

mean velocity. This error would be relatively greater in small than in large streams, however. In the measurements of the small stream a Price acoustic meter has been used, which permits the center of the meter to be placed within 3 inches of the bed of the creek.

In consideration of the above data it is believed that for ordinary streams discharging 100 cubic feet per second of water, or less, on stony beds, that 0.9 of the

mean surface velocity for the section will represent the mean velocity for that section, said surface velocities being observed at numerous points across the stream.

[a] With the object of determining the ratio between the maximum surface velocities and the mean velocity, De Prony made some experiments in wooden troughs, and Messrs. Baldwin, Whistler, and Slosson in channels lined with planks. The coefficients obtained for converting the observed surface velocity into mean velocity were 0.816 by De Prony and from 0.810 to 0.847 by the latter observers in different channels. Subsequent experiments indicate that the coefficient is generally comprised within the limits of 0.8 and 0.9, depending upon the size of the channel and the nature of the bed. The Mississippi River experiments show the coefficients to exceed 0.9, but it is quite possible that the influence of the long connecting cord and surface float caused too large values to be recorded for the velocities toward the bottom, and thus gave too high a value to the mean velocity, as Mr. Robert Gordon, in checking his experiments on the Irrawaddi with a current meter, obtained considerable reduction in the velocities approaching the bottom compared with those obtained by double floats. The coefficient would be greatest for large, deep rivers with smooth, uniform channels, and least for small, shallow streams with rough beds. Messrs. Darcy and Bazin derived from their experiments the following formula giving the relation between the maximum velocity and the mean velocity:

$$U-V=25.36\sqrt{R\,S}$$

where U is the maximum velocity in feet per second, V the mean velocity, R the hydraulic radius in feet, and S the slope.

The variation in the coefficient to be applied to the surface velocity gives rise to a possible error large enough to preclude the use of this method of measurement when accurate results are desired. As a quick method it may often be used, and in a few cases, as, for instance, at the time of high floods, when it is impossible to use other means, the results obtained by this method may be of considerable value.

The mean of 78 velocity curves taken upon rivers in the southern part of New York State, described further on in this paper, shows that the mean velocity was 0.87 of the surface velocity in the vertical section (shown in fig. 3). This coefficient varied from 0.82 in the case of Catskill Creek to 0.93 on Fishkill Creek (fig. 2). It will be noted that these coefficients apply to the mean velocity in the vertical in which the float is run. If only one surface float is used, and that in the center of the river, or point of maximum velocity, it appears that 0.8 is the proper coefficient to apply, though the chances of error are much greater than when surface floats are used at intervals across the channel.

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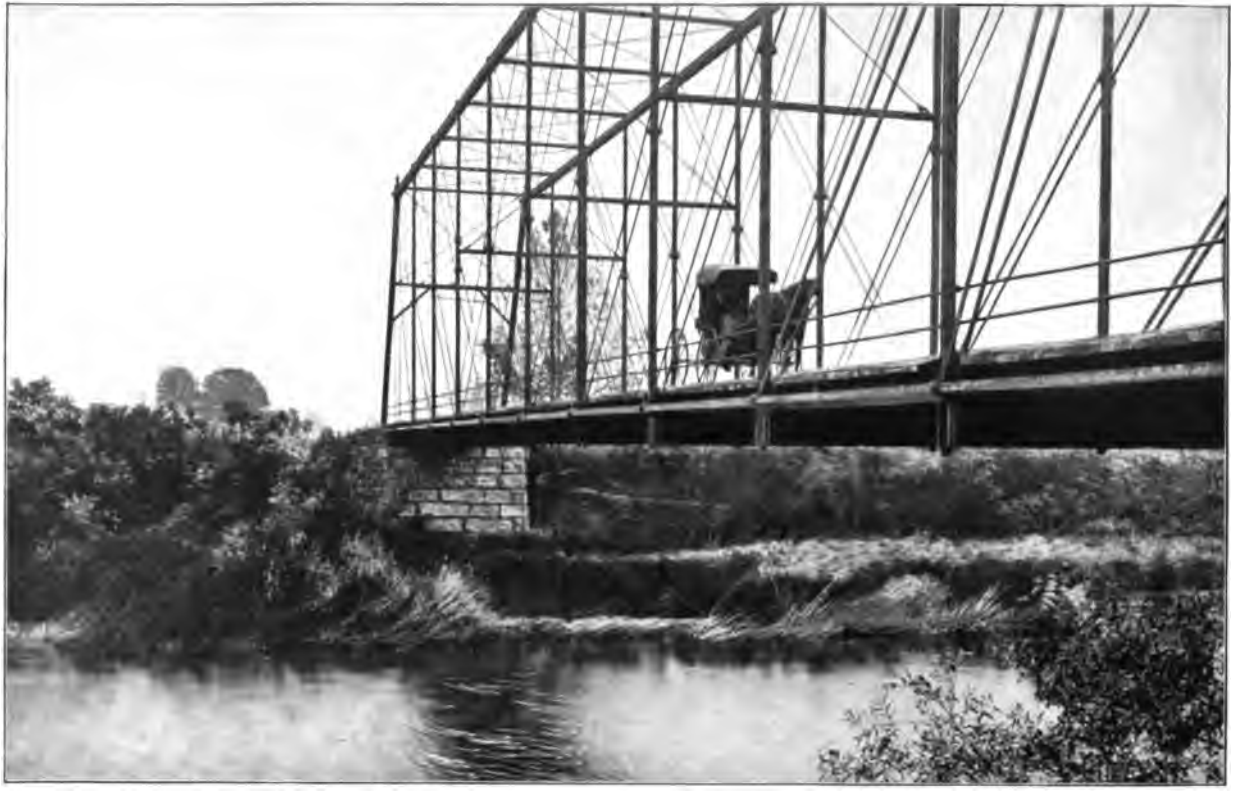
[a] From Rivers and Canals, vol. 1, p. 38, by L. F. Vernon-Harcourt.



GAGING STATION ON CATSKILL CREEK AT SOUTH CAIRO, N. Y.

GAGING STATION ON ESOPUS CREEK AT KINGSTON, N. Y.

GAGING STATION ON WALLKILL RIVER AT NEW PALTZ, N. Y.

RIVER STATIONS AT WHICH CURVES WERE OBTAINED.

In June, 1901, a reconnaissance was made of Catskill, Esopus, and Rondout creeks, and Wallkill River west of the Hudson, and Fishkill Creek and Tenmile and Housatonic rivers east of the Hudson. Nearly the entire length of each stream was traversed, and a site for a gaging station selected on each. Early in July the stations were established, with the exception of that on Tenmile River, which was established in September of the same year. Persons living near at hand were employed as gage readers to take observations of the stage of the stream twice each day. Mr. A. E. Place was in charge of these stations until September, 1901, when Mr. W. W. Schlecht was placed in charge as resident hydrographer. The measurements given in this paper were obtained by Messrs. Place and Schlecht, and the tables and several of the diagrams were prepared by Mr. Schlecht. The object of the measurements made at these stations was to determine primarily the run-off from the various drainage basins and the availability of the streams as sources of additional supply of water for New York City. The results of the measurements, together with the heights of water in the river on each day, have been published in Water-Supply Paper No. 65. Incidentally it was thought best to make observations as to the point of mean velocity in each of these streams for use in future measurements on the same rivers, as well as for general information as to the most desirable method of making current-meter measurements on rivers in general. In making measurements of rivers of this character it has been the custom of the Hydrographic Division of the United States Geological Survey to divide the cross section into partial areas of regular width, say 5 or 10 feet, and to determine the velocity in each of these small areas by holding the meter at a point six-tenths of the total depth below the surface. The velocity obtained at this point was assumed to be the mean velocity in the small area in which the meter was used. It was realized that this relation would not hold true in all streams, but in rivers with the general characteristics of those under discussion it was considered that no serious error would result from this assumption. The data in the following pages were collected in order to check the above assumption or to enable the hydrographer to determine by a point measurement the velocity at some other depth which might be considered the mean in the channel. Each of the stations established will now be briefly described. The drainage basins were described in detail in Water-Supply Paper No. 65.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

The gaging station is located at the highway bridge in the village of South Cairo, a view of which is shown on Pl. III. The total span

of the bridge is 194.5 feet between abutments, the faces of which are vertical. The stream bed is of earth for 25 feet from the right abutment. At this point the bluestone rock ledge outcrops, covered with patches of loose shingle and shifting gravel, while the left side of the channel is covered with small gravel. The entire flow of the stream at all stages passes under this bridge. High-water marks at the bridge indicate a maximum elevation of 17.5 feet on the gage. The stage of the stream is observed each morning and evening by the local gage reader, and current-meter measurements are made at intervals by the resident hydrographer.

ESOPUS CREEK AT KINGSTON, N. Y.

This gaging station was established at Washington avenue bridge in Kingston July 5, 1901, a view of which is shown in Pl. IV. This bridge has a clear span of 106.6 feet between abutments, which are nearly vertical. In addition there is on the left side a channel 19 feet in width through which water passes at high stages of the river. Gage readings are made here each morning and evening. The bed is covered with small stone over part of the channel, the rest of the bed being made up of sand, silt, and small gravel.

WALLKILL RIVER AT NEW PALTZ, N. Y.

A gaging station is situated at the New Paltz highway bridge, a view of which is given in Pl. V. The bridge is a span of 146.6 feet between the vertical faces of the masonry abutments. The entire flow passes under this bridge except in extreme freshets, when the left bank is overflowed.

The bed of the river is for the most part smooth, and composed of sand and silt.

RONDOUT CREEK AT ROSENDALE, N. Y.

A gaging station was established at the highway bridge at Rosendale, 3 miles above the junction of the Wallkill, July 6, 1901. The bridge is a single span of 136 feet, and is shown in Pl. VI. The bed of the channel is rock with bowlders for 40 feet from right bank, the rest of the bed being covered with broken rock from 6 inches to 1 foot in diameter. The entire flow, aside from the diversion to the Delaware and Hudson Canal, passes under the bridge at all stages.

FISHKILL CREEK AT GLENHAM, N. Y.

A gaging station is located at the Newburg, Dutchess and Connecticut Railroad bridge, in Glenham. It was established July 8, 1901. The bridge consists of the main central span with two auxil-

GAGING STATION ON RONDOUT CREEK AT ROSENDALE, N. Y.

GAGING STATION ON HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

iary overflow channels at the ends, the length of span being as follows: Left overflow, station zero to 22.5; main span, station 27.5 to station 122; right overflow, station 127 to station 149. The bed of the main channel is earth and gravel; that of the overflow channels is broken stone.

TENMILE RIVER BELOW DOVER PLAINS, N. Y.

A gaging station was established September 16, 1901, at Tabor's bridge, which crosses Tenmile River about 2,000 feet below the point of inflow of Swamp River. The gaging station is situated about 2 miles below Dover Plains Village. Tabor's bridge consists of a single span, 85 feet between abutments. The bridge stands square across the stream, the bed of which is sand and gravel. The entire flow passes between the abutments of this bridge, except at the time of extreme high water, which occurs nearly every spring when the river overflows its banks, and some water passes around one end of the bridge.

HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

A gaging station was established at Gaylordsville, Conn., October 24, 1900. The station is situated 3 miles east of the New York State line and 2 miles below the mouth of Tenmile River. Owing to the unfavorable conditions under the bridge, the discharge measurements are made from a cable of 200 feet span placed across the stream 1¼ miles below the bridge. A view of the river at this point is shown in Pl. VII. The cable is supported on the right bank by timber shears 25 feet high and is anchored to a large buried rock. On the left bank a sycamore tree serves as a support for the cable, which is anchored to the base of a large oak.

DISCUSSION OF TABLES.

In the tables that are given in the following pages the measurements recorded were taken at the time of the regular gagings of the rivers, and with the same degree of accuracy with which current-meter measurements have been made upon these streams. Only one instrument was used at one time, the velocity being taken at the various points in regular order vertically, usually at intervals of one-half foot. When other space intervals were used it is shown in the tables.

In Pl. VIII is shown the variation in the velocity of Wallkill River at New Paltz. The dotted lines are lines of equal velocities and are determined by observations of velocity at regular intervals throughout

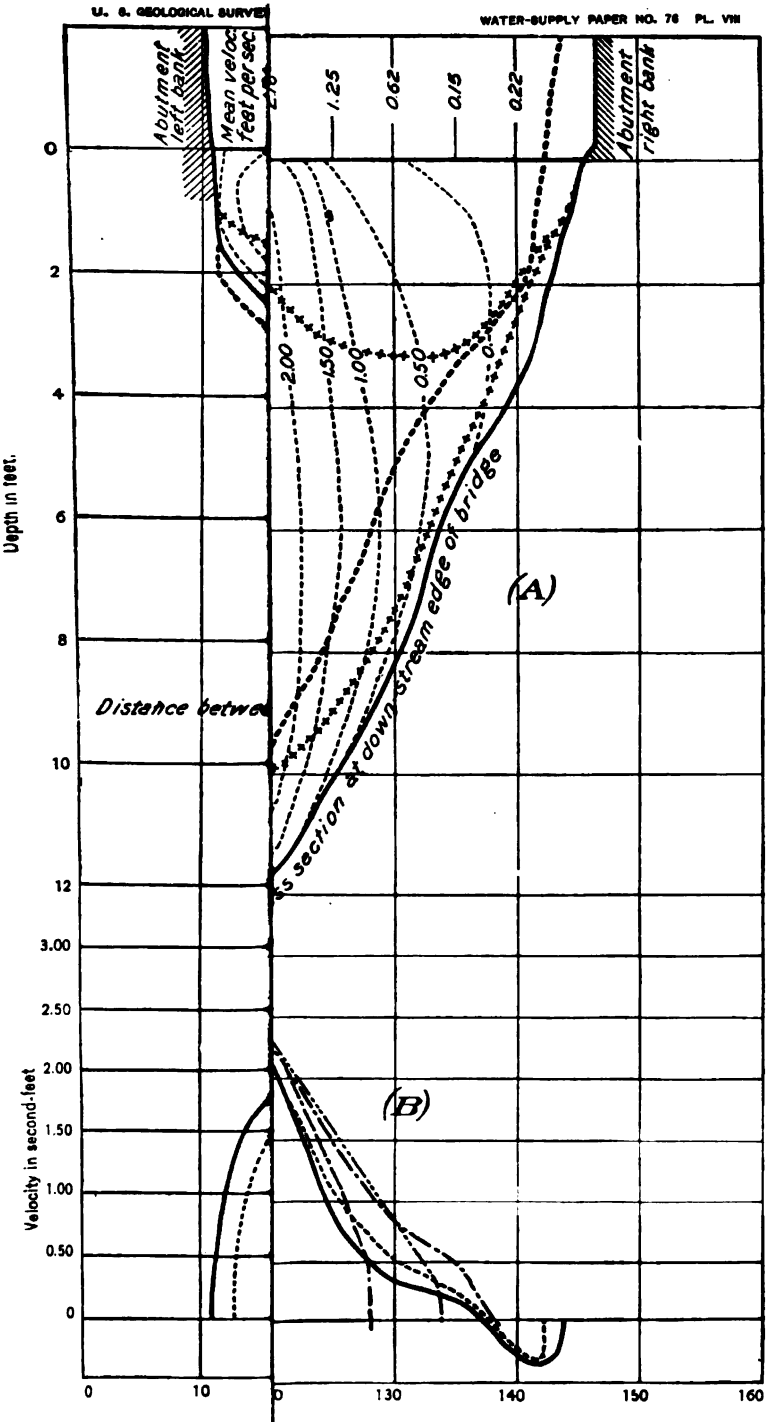
the cross section. The line marked "mean velocity for each section" shows the depth at which may be found the filament of mean velocity. Near the right bank there is slack water and some return current, which accounts for the peculiar position of the curve, and the fact that there are two lines of mean velocity. This condition would not usually occur at a gaging station.

At the bottom of Pl. VIII are lines showing the velocity at various depths, as 1 foot, 2 feet, etc., across the river section. The effect of the ledge of rocks is clearly shown in the plate.

A small Price current meter was used, and was in each case suspended from a bridge and hung freely in the water. The meter was held fifty seconds at one point to determine the velocity, and in each case the first reading was checked by a second, and if there was a discrepancy a third reading was taken. The results were plotted upon cross-section paper, the depths as ordinates and the velocities as abscissas, and a smooth curve drawn through the points, so that if in case there was an error of sufficient magnitude to affect the final results it would be found when the curve was plotted. Before the work was commenced, and after the completion of these curves, the meter was rated and showed very slight change in its readings. The gage height was read at the beginning of each measurement and at its completion, and in general no change of stage of the stream during the measurement was noted.

In Table I the date of each measurement is given at the head of the column, then the point of measurement—that is, the distance in feet from the initial point of soundings which had been previously established and marked permanently on the bridge. Next is given the gage height at the time the velocities were measured and the depth of water at the point of measurement at the time of making the measurement. The character of the bed of the river and the force and direction of the wind are also given. The depths, as given in the alternate columns, were measured by a wire attached to the meter and a tape. The column headed "Velocities" gives the actual observed velocity in feet per second at each observation.

Table II is computed from Table I, the observations being the same, but the velocities being given at regular depths as shown in percentages of the whole in the first column. The velocities as shown in the columns of this table were found from the plotted vertical velocity curves based upon the figures in Table I, the velocities at each depth being taken by scale directly from the curve. The sum of the velocities in each column of Table II divided by 10 gives the mean velocity in that section, and is the quantity that should be obtained by a single meter observation at a point in the section which represents the point of mean velocity. For comparison, the velocity as actually found at six-tenths of the depth is given at the bottom of Table II, from which



A. CROSS SECTIONS; *B*. HORIZONTAL VELOCITY CURVES ON
IN *A*.

it will at once be seen that the error in measuring the velocity at six-tenths depth is in general only slight on a stream of the general character of the Esopus.

Tables III, V, VII, IX, XI, and XIII show the results of the measurements on the Rondout, Wallkill, Catskill, Fishkill, Tenmile, and Housatonic, respectively; Tables IV, VI, VIII, X, XII, and XIV show the data obtained from the preceding tables, and were derived by the same method as Table II from Table I.

TABLE I.—*Velocities in vertical sections on Esopus Creek at Kingston.*

Date	July 19.		Aug. 10.		Aug. 19.		Aug. 29.		Aug. 29.		Aug. 29.		Sept. 6.		Sept. 6.		Sept. 21.		Sept. 26.	
Point of measurement	90.		90.		95.		75.		80.		90.		40.		80.		90.		85.	
Gage height	4.40.		4.85.		4.60.		5.50.		5.50.		5.50.		5.46.		5.46.		4.78.		4.55.	
Depth	6.4.		6.2.		5.7.		4.4.		6.1.		7.2.		2.6.		5.3.		6.6.		5.6.	
Bed of river	Silt and gravel.		Silt and gravel.		Silt and sand.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.	
Wind force	Strong.		Gentle.		Light.		Gentle.		Gentle.		Gentle.		None.		None.		Gentle.		Gentle.	
Direction of wind	Upstream.		Down-stream.		Upstream.		Down-stream.		Down-stream.		Down-stream.		.....		.....		Upstream.		Down-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.77	0.2	1.03	0.2	0.82	0.2	1.44	0.2	1.42	0.2	1.31	0.2	1.40	0.2	1.44	0.5	0.85	0.5	0.86
	.9	.77	.7	1.00	.7	.89	.7	1.45	.7	1.54	.7	1.38	.7	1.35	.7	1.47	1.0	.87	1.0	.84
	1.4	.73	1.2	1.03	1.2	.82	1.2	1.38	1.2	1.52	1.7	1.35	1.2	1.07	1.2	1.40	1.5	.87	1.5	.80
	1.9	.71	1.7	1.05	1.7	.86	1.7	1.29	1.7	1.42	2.7	1.24	1.7	1.07	1.7	1.40	2.0	.95	2.0	.85
	2.4	.70	2.2	1.00	2.2	.86	2.2	1.31	2.7	1.40	3.7	1.17	2.1	.96	2.2	1.40	2.5	.85	2.5	.80
	2.9	.66	2.7	.98	2.7	.82	2.7	1.19	3.7	1.05	4.7	.91	.....	.....	2.7	1.38	3.0	.86	3.0	.77
	3.4	.61	3.2	.91	3.2	.75	3.2	1.05	4.7	1.24	5.7	.94	.....	.....	3.7	1.20	3.5	.87	3.4	.75
	3.9	.57	3.7	.86	3.7	.68	3.7	.89	5.6	1.05	6.2	.75	.....	.....	4.2	1.16	4.0	.78	3.5	.72
	4.4	.57	4.2	.77	4.2	.67	3.9	.68	.....	.....	.....	.....	.....	.....	.....	.....	4.5	.70	4.0	.75
	4.9	.48	4.7	.75	4.7	.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.0	.65	4.5	.68
	5.4	.54	5.2	.68	5.2	.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	.48	5.1	.47
	5.9	.54	5.7	.63	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.1	.40	.....	.....

Date	Oct. 16.		Oct. 16.		Oct. 21.		Nov. 1.		Nov. 1.		Nov. 18.		Nov. 18.		Nov. 18.		Nov. 26.		Nov. 26.	
Point of measurement	40.		90.		90.		80.		95.		77.		87.		97.		95.		90.	
Gage height	6.64.		6.64.		5.56.		4.74.		4.74.		4.45.		4.45.		4.45.		5.06.		5.06.	
Depth	4.0.		8.6.		7.4.		5.0.		5.9.		4.4.		6.0.		5.0.		6.0.		6.8.	
Bed of river	Bowlders.		Silt and gravel.		Silt and gravel.		Bowlders.		Silt and sand.		Bowlders.		Silt and gravel.		Silt.		Silt.		Silt and gravel.	
Wind force	None.		None.		Gentle.		None.		None.		Gentle.		Gentle.		Gentle.		Gale.		Gale.	
Direction of wind	.....		.....		Upstream.		.....		.....		Upstream.		Upstream.		Upstream.		Downstream.		Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.5	2.26	0.5	1.89	0.5	1.42	0.5	0.98	0.5	0.85	0.5	0.85	0.5	0.80	0.3	0.67	0.5	0.97	0.5	1.04
	1.5	2.29	1.5	1.86	1.5	1.37	1.5	.92	1.5	.82	1.5	.82	1.5	.80	.8	.70	1.5	.97	1.5	1.05
	2.4	2.12	2.5	1.86	2.5	1.32	2.5	.91	2.5	.71	2.5	.77	2.5	.77	1.7	.67	2.5	.84	2.5	.91
	2.5	2.07	3.5	1.79	3.5	1.22	3.0	.91	3.5	.67	2.6	.76	3.5	.62	2.7	.57	3.6	.80	4.1	.82
	3.0	1.52	4.5	1.74	4.4	1.10	3.5	.87	3.5	.66	3.5	.60	3.6	.65	3.0	.52	4.5	.70	5.0	.67
	3.5	1.25	5.2	1.65	4.5	1.07	4.5	.60	4.5	.62	3.8	.46	4.5	.62	3.7	.51	5.5	.60	6.3	.51
	.....	.....	5.5	1.57	5.5	.97	.....	.....	5.4	.42	.....	.....	5.5	.47	4.5	.27	.....	.....	.....	.....
	.....	.....	6.5	1.42	6.5	.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	7.5	1.22	7.0	.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	8.1	1.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE II.—*Velocities at regular intervals in vertical sections on Esopus Creek, deduced from data in Table I.*

[Velocities in feet per second.]

Depth in parts of total.	July 19.	Aug. 10.	Aug. 19.	Aug. 29.	Aug. 29.	Aug. 29.	Sept. 6.	Sept. 6.	Sept. 21.	Sept. 26.	Oct. 16.	Oct. 16.	Oct. 21.	Nov. 1.	Nov. 1.	Nov. 18.	Nov. 18.	Nov. 18.	Nov. 26.	Nov. 26.
0.05	0.77	1.02	0.83	1.45	1.48	1.34	1.40	1.45	0.85	0.83	2.24	1.88	1.41	0.97	0.84	0.85	0.79	0.67	0.97	1.03
.15	.76	1.04	.87	1.44	1.51	1.38	1.38	1.46	.88	.84	2.28	1.89	1.42	.97	.85	.85	.82	.70	.98	1.04
.25	.74	1.05	.87	1.41	1.47	1.35	1.35	1.44	.90	.85	2.30	1.87	1.37	.96	.82	.84	.81	.69	.95	1.01
.35	.71	1.02	.85	1.36	1.42	1.29	1.29	1.42	.89	.83	2.29	1.84	1.30	.94	.78	.82	.78	.67	.92	.97
.45	.68	.96	.82	1.29	1.37	1.21	1.22	1.40	.86	.81	2.26	1.77	1.23	.92	.74	.80	.74	.63	.87	.92
.55	.64	.90	.77	1.22	1.30	1.13	1.64	1.37	.81	.78	2.17	1.68	1.15	.90	.68	.77	.69	.58	.92	.85
.65	.60	.83	.72	1.14	1.22	1.04	1.06	1.32	.73	.74	2.00	1.56	1.06	.87	.68	.73	.64	.52	.77	.77
.75	.56	.76	.66	1.02	1.14	.94	.98	1.25	.63	.68	1.70	1.44	.96	.83	.57	.66	.58	.44	.72	.68
.85	.52	.68	.60	.85	1.05	.83	.89	1.17	.48	.58	1.39	1.29	.85	.69	.49	.54	.52	.35	.65	.58
.95	.43	.60	.51	.56	.94	.69	.79	1.02	.27	.36	.97	1.08	.65	.45	.40	.34	.43	.25	.55	.45
Mean	.64	.89	.75	1.17	1.29	1.12	1.15	1.33	.73	.73	1.96	1.63	1.14	.85	.68	.72	.68	.55	.82	.83
.60	.63	.87	.75	1.18	1.26	1.09	1.11	1.34	.77	.76	2.08	1.63	1.11	.88	.66	.75	.67	.55	80	.81

Character of the bed: From station 0 to 86 broken rock from 0.5 feet to 1.0 foot in diameter. From station 86 to 105 smooth and even bed, composed of sand, silt, and small gravel. From 105 to 116 broken rock 0.5 feet to 1.0 foot in diameter.

TABLE III.—*Velocities in vertical sections on Rondout Creek at Rosendale.*

Date	Aug. 8.		Aug. 8.		Aug. 8.		Sept. 4.		Sept. 24		Oct. 11.		Oct. 11.		Oct. 11.		Oct. 18.		Nov. 7.		Nov. 16.		Nov. 26.		Dec. 21.	
Point of measurement	90.		105.		45.		35.		75.		65.		75.		85.		65.		80.		70.		65.		70.	
Gage height	7.50.		7.50.		7.15.		7.55.		6.45.		6.47.		6.47.		6.47.		7.08.		6.42.		6.55.		7.21.		7.60.	
Depth	7.2.		5.9.		5.2.		4.7.		5.6.		5.6.		5.6.		6.2.		6.3.		6.2.		5.6.		6.6.		6.4.	
Bed of creek	Bowlders.		Bowlders.		Bowlders.		Rock.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.	
Wind force	None.		None.		None.		Gentle.		Gentle.		Gentle.		Gentle.		Gentle.		Strong.		Gentle.		Strong.		None.		Gentle.	
Direction of wind	.....		.....		.....		Down-stream.		Down-stream.		Up-stream.		Up-stream.		Up-stream.		Down-stream.		Up-stream.		Down-stream.		.....		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*
	0.2	1.70	0.2	1.33	0.2	1.29	0.2	1.58	0.8	0.51	0.5	0.55	0.5	0.60	0.8	0.52	0.3	1.41	0.5	0.48	0.5	0.65	0.5	7.76	3.5	1.94
	.7	1.60	1.2	1.42	.7	1.40	1.2	1.52	1.0	.52	1.5	.52	1.5	.55	1.8	.50	.5	1.42	1.5	.46	1.5	.65	1.5	1.71	1.5	1.96
	1.2	1.65	2.2	1.22	1.2	1.42	2.2	1.49	2.0	.50	2.5	.52	2.5	.47	2.8	.50	1.5	1.42	2.5	.45	2.5	.60	2.5	1.70	2.5	1.89
	2.2	1.54	3.2	1.24	1.7	1.44	3.2	1.44	3.0	.47	3.4	.45	3.4	.47	3.7	.45	2.5	1.37	3.5	.43	3.4	.56	3.5	1.69	3.5	1.77
	3.2	1.33	4.2	1.05	2.2	1.40	4.2	1.19	3.4	.46	3.5	.40	3.5	.42	3.7	.45	3.5	1.35	3.7	.45	3.5	.50	4.0	1.70	3.8	1.70
	4.0	1.29	5.2	.75	3.2	1.14	.....	.....	4.0	.43	4.5	.32	4.3	.35	4.7	.40	3.8	1.22	4.6	.32	4.5	.32	5.0	1.30	1.5	1.50
	4.2	1.24	.....	.....	4.2	.89	.....	.....	5.1	.30	5.1	.37	5.1	.25	5.7	.22	4.5	1.07	5.6	.20	5.0	.20	4.0	1.04	5.5	.80
	5.2	1.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	.82	.....	.....	.....	.....	.....	.....	5.9	.62
	6.2	.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.8	5.2	.....	.....	.....	.....	.....	.....	.....	.....
	6.7	.86	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE IV.—*Velocities at regular intervals in vertical sections on Rondout Creek at Rosendale, deduced from data in Table III.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 8.	Aug. 8.	Aug. 8.	Sept. 4.	Sept. 24.	Oct. 11.	Oct. 11.	Oct. 11.	Oct. 18.	Nov. 7.	Nov. 16.	Nov. 26.	Dec. 21.
0.05	1.65	1.36	1.33	1.57	0.51	0.55	0.58	0.50	1.41	0.46	0.65	1.75	1.93
.15	1.66	1.39	1.40	1.57	.52	.55	.57	.52	1.42	.47	.65	1.76	1.97
.25	1.59	1.37	1.43	1.55	.52	.54	.56	.51	1.41	.47	.65	1.75	1.96
.35	1.50	1.34	1.40	1.53	.51	.52	.54	.50	1.40	.47	.63	1.73	1.93
.45	1.40	1.28	1.33	1.50	.49	.50	.52	.49	1.37	.46	.60	1.70	1.86
.55	1.29	1.21	1.23	1.47	.47	.46	.48	.47	1.30	.43	.55	1.66	1.77
.65	1.18	1.11	1.10	1.42	.44	.41	.44	.43	1.20	.39	.49	1.53	1.60
.75	1.07	.99	.97	1.35	.40	.36	.37	.39	1.08	.34	.39	1.37	1.35
.85	.95	.82	.83	1.28	.34	.30	.29	.32	.92	.28	.28	1.17	1.02
.95	.81	.63	.68	1.16	.26	.21	.20	.17	.59	.18	.17	.88	.61
Mean	1.31	1.15	1.17	1.44	.44	.44	.45	.43	1.21	.40	.51	1.53	1.60
.60	1.24	1.16	1.17	1.45	.46	.44	.46	.45	1.25	.41	.52	1.60	1.69

Character of bed: From station 0 to 40, rock bed with some bowlders; from station 40 to bank, broken rock from 0.5′ to 1′ in diameter.

TABLE V.—*Velocities in vertical sections on Wallkill River at New Paltz.*

Date	Aug. 10.		Oct. 1.		Oct. 9.		Oct. 24.		Oct. 24.		Nov. 9.		Nov. 16.		Nov. 16.		Nov. 16.	
Point of measurement	70.		70.		105.		80.		105.		90.		105.		90.		80.	
Gage height	10.0.		7.36.		6.48.		6.33,		6.33.		5.94.		6.50.		6.50..		6.50.	
Depth	9.8.		7.5.		7.8.		6.4.		7.6.		6.2.		7.8.		6.6.		6.4.	
Bed of river	Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.	
Wind force	Gentle.		Gentle.		Fresh.		Fresh.		Fresh.		Gentle.		Fresh.		Fresh.		Fresh.	
Direction	Downstream.		Downstream.		Downstream.		Upstream.		Upstream.		Downstream.		Downstream.		Downstream.		Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	3.00	0.3	1.79	0.5	1.22	0.3	0.89	0.5	0.95	0.5	0.62	0.5	1.21	0.5	1.20	0.5	1.16
	1.0	3.05	1.3	1.70	1.5	1.15	0.8	.91	1.5	.97	1.5	.55	1.5	1.11	1.5	1.17	2.0	1.05
	2.0	2.77	2.3	1.67	2.5	1.12	1.5	.86	2.5	.92	2.5	.50	2.5	1.05	2.5	1.05	3.0	.92
	3.0	2.91	3.3	1.60	3.5	1.12	2.5	.77	3.5	.95	3.5	.42	3.5	1.05	3.5	.89	3.8	.90
	4.0	2.86	4.3	1.50	4.5	1.08	3.5	.70	4.5	.92	3.7	.46	4.5	1.05	4.0	.91	5.0	.72
	5.0	2.86	4.5	1.52	4.7	1.05	3.8	.75	4.6	.92	4.5	.36	4.7	1.07	4.5	.81	5.9	.66
	6.0	2.58	5.3	1.40	5.5	.97	4.5	.65	5.5	.82	5.7	.26	5.5	.91	5.5	.62	.....	.....
	7.0	2.47	6.3	1.32	6.5	.87	5.5	.47	6.5	.73	.....	.....	6.5	.80	6.1	.54	.....	.....
	8.0	2.35	6.9	1.15	7.3	.50	5.8	.37	7.1	.60	.....	.....	7.3	.60	.....	.....	.....	.....
	9.0	1.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VI.—*Velocities at regular intervals in vertical sections on Wallkill River at New Paltz, deduced from data in Table V.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 20.	Oct. 1.	Oct. 9.	Oct. 24.	Oct. 24.	Nov. 9.	Nov. 16.	Nov. 16.	Nov. 16.
0.05	3.00	1.77	1.23	0.90	0.94	0.62	1.20	1.20	1.16
.15	3.04	1.75	1.18	.90	.97	.59	1.15	1.18	1.13
.25	2.99	1.70	1.14	.87	.97	.56	1.13	1.15	1.08
.35	2.91	1.65	1.12	.83	.96	.53	1.10	1.08	1.03
.45	2.82	1.59	1.10	.79	.94	.49	1.07	1.01	.97
.55	2.72	1.52	1.07	.75	.92	.45	1.02	.93	.91
.65	2.60	1.45	1.03	.69	.86	.40	.97	.83	.84
.75	2.44	1.37	.95	.63	.80	.35	.90	.73	.77
.85	2.20	1.27	.82	.53	.71	.30	.77	.61	.68
.95	1.88	1.13	.46	.35	.53	.24	.49	.48	.58
Mean	2.66	1.52	1.01	.724	.86	.453	.98	.92	.91
.60	2.66	1.49	1.05	.72	.89	.43	1.00	.88	.88

Character of bed of stream: At all of the above stations the bed of the creek is smooth, composed of sand and silt.

TABLE VII.—*Velocities in vertical sections on Catskill Creek at South Cairo.*

Date	July 20		July 25		July 25		Aug. 1.		Aug. 1.		Aug. 9.		Aug. 23.		Sept. 2.		Sept. 2.		Sept. 7.		Sept. 23.		Oct. 22.		Nov. 8.		Sept. 2.	
Point of measurement	55.		55.		45.		55,		60.		50.		60.		35.		40.		35.		55.		30.		50.		60.	
Gage height	3.60.		3.00.		3.00.		2.80.		2.80.		3.00.		3.12.		3.00.		3.00.		2.92.		2.74.		2.82.		2.70.		3.00.	
Depth	3.6.		2.9.		3.6.		2.7.		2.7.		3.1.		2.9.		4.4.		3.9.		4.3.		2.7.		2.3.		2.9.		3.0.	
Bed of creek	Rock.		Rock.		Rock.		Rock.		Gravel.		Rock.		Gravel.		Gravel.		Gravel.		Rock.		Gravel.		Rock.		Rock.		Gravel.	
Wind force	None.		Gentle.		Gentle.		Strong.		Strong.		Gentle.		Gentle.		Gentle.		Gentle.		.....		.....		.....		Fresh.		Gentle.	
Direction	.....		Down-stream.		Down-stream.		Down-stream.		Down-stream.		Up-stream.		Down-stream.		Up-stream.		Up-stream.		None.		None.		None.		Down-stream.		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.2	1.67	0.2	0.75	0.2	0.66	0.2	0.52	0.2	0.48	0.2	0.61	0.3	1.05	0.2	0.61	0.2	0.73	0.2	0.48	0.2	0.48	0.2	0.37	0.5	0.37	0.2	0.77
	.5	1.72	.5	.77	.5	.63	.5	.50	.5	.48	.7	.67	.8	1.03	.7	.59	.7	.71	.7	.50	.7	.42	.7	.36	1.0	.35	.6	.75
	1.0	1.54	1.0	.75	1.0	.66	1.0	.45	1.0	.43	1.2	.66	1.3	.99	1.2	.52	1.2	.69	1.2	.41	1.2	.35	1.2	.32	1.5	.30	1.1	.73
	1.5	1.52	1.5	.63	1.5	.57	1.5	.43	1.5	.36	1.7	.59	1.8	.73	1.7	.50	1.7	.61	1.7	.43	1.6	.35	1.4	.31	1.7	.31	1.6	.54
	2.0	1.47	1.7	.59	2.0	.57	1.6	.43	1.6	.38	2.0	.50	2.3	.57	2.2	.43	2.2	.63	2.7	.29	1.7	.25	1.8	.27	2.0	.28	2.1	.54
	2.5	1.21	2.0	.52	2.2	.61	2.0	.36	2.0	.25	2.2	.54	2.8	.34	2.7	.38	2.7	.61	3.8	.23	2.2	.17	.....	.....	2.4	.25	2.6	.36
	3.0	1.07	2.4	.45	2.5	.50	2.2	.25	2.2	.25	2.7	.54	.....	.....	3.2	.29	3.2	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3.1	1.13	.....	.....	3.0	.50	.....	.....	.....	.....	.....	.....	.....	.....	3.7	.22	3.7	.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VIII.—*Velocities at regular intervals in vertical sections on Catskill Creek at South Cairo, deduced from data in Table VII.*

[Velocities in feet per second.]

Depth in parts of total.	July 20.	July 25.	July 25.	Aug. 1.	Aug. 1.	Aug. 9.	Aug. 23.	Sept. 2.	Sept. 2.	Sept. 7.	Sept. 23.	Oct. 22.	Nov. 8.	Sept. 2.
0.05	1.69	0.75	0.64	0.52	0.48	0.65	1.06	0.60	0.72	0.48	0.47	0.37	0.37	0.77
.15	1.70	.76	.65	.51	.49	.68	1.05	.59	.71	.49	.44	.38	.37	.76
.25	1.65	.76	.65	.50	.47	.68	1.03	.56	.70	.46	.41	.37	.36	.75
.35	1.58	.73	.63	.48	.44	.67	.98	.51	.68	.43	.38	.36	.35	.73
.45	1.50	.68	.60	.45	.41	.65	.92	.46	.66	.39	.35	.34	.33	.68
.55	1.41	.62	.57	.42	.37	.61	.84	.40	.64	.35	.32	.32	.31	.61
.65	1.32	.56	.54	.38	.32	.57	.74	.34	.62	.31	.28	.30	.29	.53
.75	1.21	.50	.50	.32	.27	.52	.62	.28	.59	.26	.23	.28	.26	.45
.85	1.10	.43	.46	.26	.21	.47	.50	.22	.56	.20	.17	.25	.23	.37
.95	.94	.36	.40	.18	.14	.40	.36	.14	.52	.13	.10	.19	.19	.25
Mean	1.41	.61	.564	.40	.36	.59	.81	.41	.64	.35	.31	.31	.31	.59
.60	1.37	.59	.56	.40	.35	.59	.80	.37	.63	.33	.30	.31	.30	.57

Character of river bed: From station 0 to 55 the bed is a rock ledge, and from station 55 to the left bank it is small gravel, none over 0.2 foot in diameter.

TABLE IX.—*Velocities in vertical sections on Fishkill Creek at Glenham.*

Date	July 24.		Aug. 15.		Aug. 15.		Aug. 30.		Aug. 30.		Aug. 30.		Sept. 6.		Sept. 6.		Sept. 27.		Oct. 5.		Oct. 25.		Nov. 11.		Nov. 20.	
Point of measurement	51.		50.		55.		45.		50.		55.		60.		65.		75.		55.		85.		55.		50.	
Gage height, feet	3.60.		3.85.		3.85.		4.60.		4.60.		4.60.		4.15.		4,15.		3.86.		3.98.		4.05.		3.85.		3.95.	
Depth	3.6.		4.0.		3.4.		4.4.		4.4.		4.2.		3.8.		3.2.		2.9.		3.5.		2.8.		3.4.		4.0.	
Bed of creek	Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.	
Wind	Gentle.		Strong.		Strong.		Gentle.		Gentle.		Gentle.		None.		None.		Gentle.		Gentle.		Fresh.		None.		Gentle.	
Direction	Up-stream.		Down-stream.		Down-stream.		Down-stream.		Down-stream.		Down-stream.		.....		.....		Down-stream.		Down-stream.		Up-stream.		.....		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.2	0.54	0.2	0.75	0.2	0.73	0.2	1.70	0.2	1.42	0.2	1,47	0.2	1.05	0.2	1.21	0.3	0.66	0.4	0.93	0.3	1.05	0.4	0.62	0.5	0.69
	.7	.54	.7	.75	.7	.75	.7	1.89	.7	1.77	.7	1.75	.7	1.17	.7	1.24	.8	.64	.9	.90	.8	1.02	.9	.60	1.0	.64
	1.2	.45	1.2	.73	1.2	.71	1.2	1.87	1.2	1.75	1.2	1.70	1.2	1.17	1.2	1.17	1.3	.61	1.4	.87	1.3	.97	1.9	.56	1.7	.65
	1.7	.38	1.7	.68	1.7	.68	1.7	1.96	1.7	1.72	1.7	1.67	1.7	1.14	1.7	1.14	1.7	.56	1.9	.87	1.7	.97	2.0	.57	2.4	.65
	2.2	.38	2.2	.66	2.2	.63	2.2	1.79	2.2	1.67	2.2	1.61	2.2	1.03	2.2	.98	1.8	.57	2.1	.85	2.3	.67	2.9	.42	2.9	.59
	2.7	.29	2.4	.66	2.7	.59	2.7	1.75	2.7	1.61	2.7	1.54	2.7	.94	2.9	.50	2.3	.46	2.5	.85	.....	.....	.....	.....	3.5	.54
	3.1	.27	2.7	.54	.....	.....	3.2	1.61	3.2	1.52	3.2	1.54	3.3	.73	.....	.....	.....	.....	3.0	.70	.....	.....	.....	.....	.....	.....
	.....	.....	3.2	.45	.....	.....	3.7	1.49	3.7	1.30	3.7	1.38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	.....	.....	.....	.....	3.9	1.29	3.9	1.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE X.—*Velocities at regular intervals in vertical sections on Fishkill Creek at Glenham, deduced from data in Table IX.*

[Velocities in feet per second.]

Depths in parts of total.	July 24.	Aug. 15.	Aug. 15.	Aug. 30.	Aug. 30.	Aug. 30.	Sept. 6.	Sept. 6.	Sept. 27.	Oct. 5.	Oct. 25.	Nov. 11.	Nov. 20.
0.05	0.54	0.75	0.74	1.77	1.64	1.63	1.06	1.21	0.67	0.95	1.05	0.62	0.67
.15	.54	.75	.75	1.87	1.74	1.71	1.15	1.22	.66	.93	1.05	.62	.68
.25	.51	.74	.74	1.92	1.75	1.71	1.18	1.21	.65	.90	1.04	.61	.67
.35	.47	.72	.72	1.91	1.73	1.68	1.16	1.19	.63	.88	1.02	.60	.66
.45	.43	.68	.70	1.86	1.69	1.64	1.12	1.16	.61	.87	1.00	.59	.65
.55	.39	.63	.67	1.78	1.64	1.60	1.06	1.11	.58	.86	.97	.57	.64
.65	.34	.56	.63	1.69	1.58	1.56	.98	1.02	.55	.85	.89	.54	.62
.75	.29	.48	.59	1.59	1.50	1.51	.88	.88	.52	.81	.80	.50	.58
.85	.23	.40	.55	1.45	1.38	1.44	.76	.70	.45	.75	.67	.44	.54
.95	.16	.30	.51	1.26	1.15	1.32	.62	.50	.35	.65	.53	.35	.49
Mean	.39	.60	.66	1.71	1.58	1.58	1.00	1.02	.57	.85	.90	.54	.62
.60	.37	.60	.65	1.74	1.61	1.58	1.02	1.07	.57	.86	.93	.56	.63

Character of bed of creek: Bowlders from 0.2 foot to 0.6 foot in diameter.

TABLE XI.—*Velocities in vertical sections on Tenmile River at Dover Plains.*

Date	Oct. 15.		Oct. 26.		Oct. 26.		Nov. 11.		Nov. 22.	
Point of measurement	55.		25.		55.		25.		25.	
Gage height	7.19.		5.01.		5.01.		4.75.		4.76.	
Depth	6.8.		4.6.		4.8		4.4.		4.2.	
Bed of creek	Sand.		Sand.		Sand.		Sand.		Sand.	
Wind	Fresh.		None.		None.		None.		Gentle.	
Direction	Downstream.								Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	2.43	0.3	1.10	0.5	1.00	0.4	0.90	0.3	0.84
	1.5	2.38	.8	1.07	1.5	.95	.9	.87	.8	.84
	2.5	2.31	1.3	1.00	2.5	.93	1.4	.77	1.5	.73
	3.5	2.19	1.8	.92	2.9	.92	2.0	.70	2.0	.75
	4.1	2.17	2.3	.90	3.5	.90	2.6	.67	2.5	.67
	4.4	2.09	2.8	.82	4.3	.77	3.0	.61	3.0	.56
	5.3	2.00	3.3	.75			3.5	.55	3.5	.55
	6.3	1.84	4.1	.62			3.9	.50	3.7	.49

TABLE XII.—*Velocities at regular intervals in vertical sections on Tenmile River at Dover Plains, deduced from data in Table XI.*

[Velocities in feet per second.]

Depths in parts of total.	Oct. 15.	Oct. 26.	Oct. 26.	Nov. 11.	Nov. 22.
0.05	2.44	1.08	0.99	0.89	0.84
.15	2.42	1.06	.99	.86	.84
.25	2.36	1.03	.98	.83	.82
.35	2.30	.98	.97	.79	.78
.45	2.23	.93	.95	.75	.74
.55	2.16	.87	.93	.70	.70
.65	2.09	.81	.91	.64	.65
.75	2.02	.73	.88	.58	.59
.85	1.95	.65	.82	.52	.51
.95	1.83	.46	.68	.44	.43
Mean	2.18	.86	.91	.70	.69
.60	2.13	.84	.92	.67	.68

TABLE XIII.—*Velocities in vertical sections on Housatonic River at Gaylordsville.*

Date	Aug. 8.	Oct. 29.	Nov. 13.	Nov. 23.
Point of measurement	60.	60.	60.	60.
Gage height	3.50.	4.05.	4.82.	4.11.
Depth	3.8.	4.8.	6.2.	4.8.
Bed of creek	Gravel.	Gravel.	Gravel.	Gravel.
Wind	None.	None.	Very strong.	Gentle.
Direction			Downstream.	Upstream.

Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
0.20	2.19	0.5	2.98	0.5	3.84	0.5	3.08
.30	2.23	1.5	2.90	1.5	3.93	1.5	2.92
.8	2.25	2.5	2.85	2.5	3.84	2.5	2.81
1.3	2.14	2.9	2.68	3.5	3.50	2.9	2.61
1.8	2.07	3.5	2.39	3.7	3.44	3.5	2.38
2.3	2.05	4.3	1.92	4.5	3.23	4.3	1.90
2.8	1.72			5.6	2.50		
3.3	1.35						

TABLE XIV.—*Velocities at regular intervals in vertical sections on Housatonic River at Gaylordsville, deduced from data in Table XIII.*

[Velocities in feet per second.]

Depths in parts of total.	Aug. 8.	Oct. 29.	Nov. 13.	Nov. 23.
0.05	2.21	3.00	3.89	3.02
.15	2.23	2.97	3.90	3.01
.25	2.21	2.94	3.91	3.00
.35	2.17	2.90	3.89	2.94
.45	2.10	2.85	3.79	2.85
.55	2.02	2.77	3.60	2.72
.65	1.85	2.57	3.38	2.52
.75	1.66	2.35	3.11	2.34
.85	1.45	2.10	2.79	2.10
.95	1.20	1.75	2.04	1.80
Mean	1.91	2.62	3.43	2.63
.60	1.94	2.67	3.49	2.62

For the purpose of comparison a mean curve for each of the streams has been determined by taking the mean of all the velocities shown in each of Tables II, IV, VI, VIII, X, XII, and XIV. To facilitate comparison, the data for these mean curves have been expressed in percentages of the mean velocity in a vertical section, and are shown in Table XV, the total number of curves being 78. By this arrangement a figure in the column greater than 100 shows a velocity greater than the mean in the vertical section being considered, and a velocity less than 100 shows a velocity less than the mean. The mean curves have been plotted in fig. 2. It will be seen from these curves that the general character of the vertical velocity curves is much the same in each

case, showing fairly conclusively that we may prophesy as to the general character of the vertical velocity curve in natural streams with steep banks and from smooth to moderately rough bottoms, and depths of from 3 to 8 feet. It will be noted that the ratio of the mean velocity to the surface velocity varies from 92 per cent on the Fishkill to 82 per cent on the Catskill, and that the maximum velocity of these streams varies from 13 to 25 per cent greater than the mean, and that at no point do all of the curves fall so closely together as at six-tenths depth. At that point the greatest variation from the mean is 2½ per cent. This shows that the measurements made at six-tenths depth were subject to less variation than those made at any other point, and that in general, on streams of the character here represented, a measurement made at that point would represent approximately the mean velocity in the section. It will be noted that none of the curves cross the line of mean velocity at a greater depth than 0.63, nor at a less depth than 0.56, showing that the point of mean velocity on these streams lies between these two depths.

TABLE XV.—*Averages of velocity curves expressed in terms of mean velocity in a vertical section (represented as 100).*

Stream	Esopus.			Rondout.	Wallkill.	Catskill.	Fishkill.	Tenmile.	Housatonic.	Average of all the streams.
No. of velocity curves.	12.	8.	20.	13.	9.	14.	13.	5.	4.	78.
Bed of stream	Small gravel.	Bowlders.	Average.	Bowlders.	Silt.	Small gravel and rock ledge.	Large gravel.	Sand.	Gravel.	Various.
Mean depth	6.5.	4.7.	5.8.	6.	7.3.	3.2.	3.7.	5.	4.9.	5.07.
Depth below surface in parts of total:										
0.05	118.6	115.9	117.3	117.9	119.7	124.7	110.7	116.8	114.4	117.0
.15	120.8	116.6	118.8	119.6	118.4	124.8	113.7	115.6	114.3	117.9
.25	118.9	115.5	117.3	118.5	115.4	121.8	113.4	112.7	113.9	116.3
.35	115.0	112.7	113.9	115.9	111.6	116.5	111.3	109.0	112.4	113.2
.45	109.3	109.4	109.3	111.7	107.4	109.7	108.2	104.9	109.5	109.0
.55	102.3	104.8	103.5	105.9	102.5	101.5	104.0	100.4	105.0	103.6
.65	94.4	98.6	96.4	97.2	96.3	92.5	98.3	95.5	97.4	96.5
.75	85.5	89.7	87.5	86.3	89.0	81.9	91.0	89.9	89.3	87.9
.85	74.9	77.8	76.3	72.8	78.6	70.7	81.2	83.3	79.7	77.2
.95	60.3	59.0	59.7	54.2	61.1	55.9	68.2	71.9	64.1	61.4
Mean	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
.60	98.9	101.7	100.2	101.8	99.6	97.2	101.4	98.1	101.2	100.26

In Table XV, under the heading "Average of all the streams," the mean velocity of each depth given in the table is shown, and the curve representing this mean vertical velocity curve is platted in fig. 3 as a solid line. This curve represents the mean of 78 vertical velocity curves, the mean of the vertical velocity curves platted in fig. 2.

It will be noted in this curve that the relation between the mean velocity and the surface velocity is 87; that the maximum velocity is 18 per cent greater than the mean, and that the point of mean velocity is almost exactly at six-tenths depth, the variation, as shown in the last column of Table XV, being about one-fourth of 1 per cent. This shows clearly that a measurement made at six-tenths of the depth of a stream having the general characteristics of those considered will in general represent closely the mean velocity in that section.

To show the relation between the velocity at mid depth and the mean velocity in a vertical section Table XVI has been compiled from Table XV. From this table it will be seen that, upon streams like these being considered, if the mid depth is known, the mean velocity in the vertical section may be found by applying a coefficient of 0.94.

TABLE XVI.—*Relation between velocity at mid depth to mean velocity in a vertical section.*

Stream.	Velocity at mid depth expressed in percentage of the mean.	Coefficient to be applied to velocity at mid depth to obtain mean velocity.
Esopus	106.4	0.94
Rondout	108.8	.92
Wallkill	104.9	.95
Catskill	105.6	.94
Fishkill	106.1	.94
Tenmile	102.6	.97
Housatonic	107.2	.93
Average	106.3	.94

Humphreys's and Abbott's observations on the Mississippi River gave a coefficient of 0.98, while Ellis, on the Connecticut, found 0.94, and Wheeler and Lynch, on the Merrimac flume, found 0.95. It will be seen that there is a variation of 5 per cent on the streams being considered in this paper, and that the results of Humphreys and Abbott on the Mississippi and Ellis on the Connecticut vary from each other by 4 per cent, although the rivers are both large and have somewhat the same characteristics. In view of these facts, it seems that it is somewhat better to measure the velocity at the point of mean velocity than to measure the velocity at mean depth and apply a coefficient.

It is very evident that the character of the bed will affect to some extent the form of the vertical velocity curve. A rough bed would be expected to retard the velocity near the bottom of the stream. None of the streams under investigation may be considered to have extremely rough beds, but by comparison the beds of Rondout Creek

and Housatonic River may be said to be rough, while those of the Wallkill River and Tenmile Creek are smooth at the point of measurement. Part of the bed of the Esopus is rough and part smooth. In order to determine the effect of the variation in the beds on the flow, the results in Table XV have been classified in Table XVII into streams with rough and smooth bottoms, the Rondout, Housatonic, and part of the curves on the Esopus being in the first column, and the Wallkill, Tenmile, and remaining observations on the Esopus in the second. The results shown in these two columns have been plotted in fig. 3.

It will be seen that the rough bed causes a drag at the lower end of the vertical velocity curve, due largely to eddies formed at the bottom of the stream. This retardation of the water near the bed of the stream causes the point of mean velocity in the vertical section to rise, and a measurement of velocity made at 0.60 depth will therefore be too small. With a smooth bed a measurement made at 0.60 depth will, in general, be too large, the filament of mean velocity being nearer the surface. In other words, in making a measurement of mean velocity in a vertical section the meter should, in general, be suspended above 0.60 depth in streams of rough bed and below 0.60 depth in streams of smooth bed. In the rivers here considered the variation of roughness of beds is so small in the different streams that the error in assuming the velocity at 0.60 depth to be the mean velocity in the vertical section would not be great, but in streams of very rough beds the variation would be more marked.

TABLE XVII.—*Relation between velocities in vertical sections with smooth and rough bottoms.*

Depth below surface—in parts of total.	Smooth bottom: Esopus, Wallkill, Tenmile.	Rough bottom: Rondout, Housatonic.
	Velocity in percentage of the mean.	*Velocity in percentage of the mean.*
0.05	118.7	116.2
.15	118.8	117.0
.25	116.2	116.0
.35	112.4	113.8
.45	107.6	110.3
.55	102.0	105.3
.65	95.4	97.7
.75	87.8	88.3
.85	78.1	76.5
.95	63.0	58.9
Mean	100.0	100.0
.60	99.0	101.6

FLOW OF RIVERS UNDER ICE, SMOOTH AND UNBROKEN COVER.

It is frequently desirable to measure the flow of rivers and canals when they are covered with a coating of ice. It is quite clear that the same relations in various parts of the channel do not hold good when the channel is covered with ice as when the surface is open. The friction between the water and the ice retards the surface velocity, and it is possible that in a few cases the river may flow under a head if the ice cake is heavy and held firmly in position. In making measurements of the flow of a river when frozen over, floats can not be used, and in general a current meter is the most serviceable instrument.

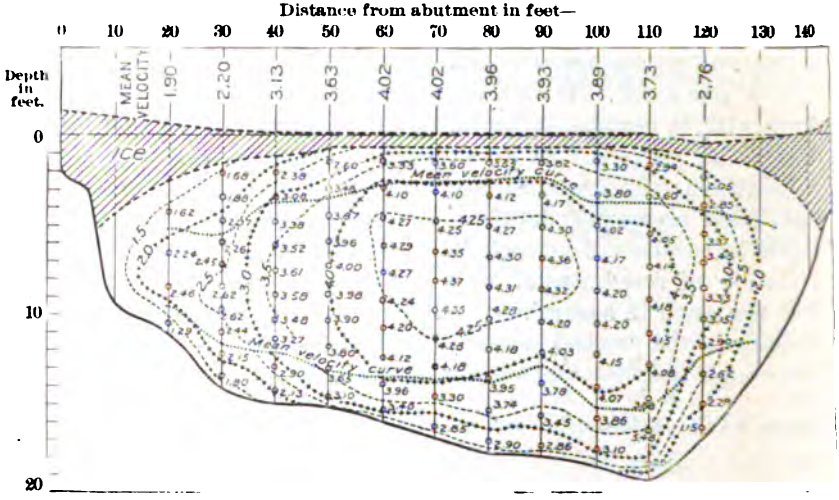


FIG. 4.—Cross section of Wallkill River at New Paltz, showing ice cover and curves of equal velocity in river channel. (Note.—Measurements taken January 23, 1902; 117 measurements of velocity being made with the current meter; mean velocity, 3.23 feet per second; discharge, 6,063 second-feet. The dotted line shows the position of mean velocity in the vertical section.)

During the winter of 1901–2 observations to determine the change of velocity in a vertical plane below the ice were made on Wallkill River, and Esopus, Rondout, and Catskill creeks, and the data collected are presented in the following tables.[a] The observations were made by cutting holes through the ice large enough to admit a current meter. The thickness of the ice in each case is given in the table, and the fact that the water rose in most cases to a point about flush with the surface of the ice shows that there was some pressure upon the flowing stream. It may be of interest in passing to note the distribution of the velocity in the cross section, as shown in fig. 4, the result of the gagings made on the Wallkill River at the New Paltz gaging station, January 23, 1902. The total area of the water section was 1,880 square feet, the mean velocity 3.23, and the discharge 6,063 second-feet. One hundred and seventeen measurements were

[a] These observations were made incidental to the discharge measurements of the streams.

made with the current meter, and the points are platted in the figure, the velocity in feet per second being noted beside each point. The mean velocity in feet per second in a vertical section is shown by the figures across the top of the section. A dotted line showing the position of the mean velocity in the vertical sections has been drawn on the cross section. It will be seen that the maximum velocity occurs near the center of the channel, and at about mid depth, and that the effect of the ice covering is to form a covered flume, the curves of equal velocity being much the same as have been plotted occasionally for such flumes. The water just below the ice is so retarded that there are two points of mean velocity, as shown in figs. 4 and 5.

In the following tables are given the results of measurements made in vertical sections upon the above-mentioned rivers. These measurements were made with a single meter, the velocities being taken at intervals of from 1 to 2 feet, these distances being shown in each case in the table. Tables XVIII, XX, XXII, XXIV, and XXVI show the velocities as determined by actual measurements. At the head of the table are given the date, distance from initial point of sounding, gage height at the time of measurement, total depth of the river (including ice), the thickness of ice, and the depth of water under the ice. In every case the depth, as given in the body of the table, refers to the depth of water under the ice, the lower surface of the ice being considered as zero, and the distances being measured in feet and tenths. Where not otherwise stated, the ice was smooth on the lower side. Some curves were made with ice broken and tilted, but the results were quite different from those obtained with smooth ice, and the results have been given in separate tables (XXIX to XXXIII). The retarding influence of the rough ice was decidedly greater than that of the smooth ice and is so variable that no law can be formulated.

Tables XIX, XXI, XXIII, XXV, and XXVII are derived from the preceding tables by platting the vertical velocity curves, as shown by the original data, and taking from this curve the velocities at regular intervals, one-tenth of the depth apart. The sum of these velocities divided by 10 will give the mean in the section.

In Table XIX, and the others of a similar character, a column has been added, headed "Per cent of mean." The figures of this column are obtained by dividing the corresponding figures in the adjacent column by the mean velocity, which reduces the data for each velocity curve to a similar curve whose mean is 100, and as the depths are then expressed as percentages of total depth, and the velocities as percentages of the mean velocity, the comparison between the curves is facilitated. In all cases for which the data are included within these tables the ice on the surface was smooth both on its upper and lower faces. The few velocity curves taken at times when the ice was broken and tilted are shown in separate tables.

TABLE XVIII.—*Velocities in vertical sections under ice on Wallkill River.*[a]

1901-1902.

Date	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
Point of measurement	85.		75.		53.		40.		50.		80.		90.		100.		40.		50.		60.		70.		80.	
Gage height	11.50.		11.50.		11.50.		11.50.		7.24.		7.24.		7.24.		7.24.		17.33.		17.33.		17.33.		17.33.		17.33.	
Total depth	12.3.		12.2.		9.9.		9.4.		4.6.		6.8.		7.6.		8.8.		15.4.		16.0.		14.8.		16.8.		17.7.	
Thickness of ice	0.7.		0.7.		0.7.		0.4.		1.2.		1.0.		1.0.		1.0.		1.4.		1.0.		0.8.		0.8.		0.7.	
Depth of water	11.6.		11.5.		9.2.		9.0.		3.4.		5.8.		6.6.		7.8.		14.6.		15.0.		14.0.		16.0.		17.0.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.8	2.52	0.8	2.43	0.8	2.14	0.3	2.24	0.3	0.80	0.3	0.77	0.3	0.62	0.3	0.87	0.5	2.21	0.5	2.61	0.4	3.23	0.4	3.15	0.3	1.45
	2.8	3.03	2.8	3.13	2.8	2.68	1.3	2.64	1.3	.95	1.3	1.12	1.3	1.22	1.3	1.15	1.5	3.13	1.4	3.50	1.3	3.91	1.2	3.72	1.0	3.37
	4.8	3.11	4.8	3.18	4.8	2.68	3.3	2.90	2.3	.85	2.3	1.22	2.3	1.25	2.3	1.25	3.5	3.37	2.2	3.84	2.3	4.19	2.8	4.12	2.6	4.12
	6.8	2.78	6.8	2.73	6.8	2.71	5.2	2.76	2.8	.67	3.3	1.12	3.3	1.20	3.3	1.27	5.5	3.55	3.8	3.93	4.2	4.30	4.4	4.21	4.2	4.26
	8.8	2.38	8.8	2.43	8.7	2.12	7.0	2.31	.....	.....	4.3	1.00	4.3	1.05	4.3	1.22	7.5	3.60	5.7	3.93	6.0	4.26	5.8	4.32	5.8	4.28
	10.8	1.62	11.0	1.65	.....	.....	8.5	1.62	.....	.....	5.3	.77	5.3	.87	5.3	1.15	9.5	3.41	7.6	3.95	7.9	4.23	7.4	4.37	7.4	4.32
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.1	.70	6.3	.95	11.5	3.03	8.5	3.97	9.8	4.19	9.0	4.35	9.0	4.30
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.3	.70	13.5	1.96	9.3	3.97	11.7	4.12	10.5	4.26	10.5	4.23
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.2	3.97	12.6	3.79	12.0	4.21	12.0	4.07
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	11.0	3.95	13.5	3.18	13.6	4.02	13.5	3.88
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.0	3.74	.....	.....	14.2	3.84	15.0	3.60
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.8	3.48	.....	.....	14.9	3.08	15.8	3.06
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.7	3.01	.....	.....	15.5	2.36	16.5	2.43
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.5	2.24	.....	.....	.....	.....	.....	.....

Date	Jan. 23.		Jan. 23.		Jan. 23.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
Point of measurement	90.		100.		110.		40.		70.		80.		90.		100.		80.		90.		90.		80.		40.	
Gage height	17.33.		17.33.		17.33.		9.07.		9.07.		9.07.		9.07.		9.07.		7.78.		7.78.		7.33.		7.33.		7.33.	
Total depth	17.7.		18.8.		19.8.		6.8.		8.8.		8.8.		10.0.		11.5.		7.5.		8.5.		8.0,		7.3.		5.9.	
Thickness of ice	0.7.		0.8.		0.8.		1.0.		1.0.		1.0.		1.0.		1.2.		1.0.		1.0.		2.0.		2.0.		2.4.	
Depth of water	17.0.		18.9.		19.0.		5.8.		7.8.		7.8.		9.0.		10.8.		6.5.		7.5.		6.0.		5.8.		3.5.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.3	3.23	0.3	2.36	0.7	2.73	0.3	1.32	0.4	1.98	0.3	1.65	0.3	1.70	0.3	1.77	0.3	1.10	0.3	1.15	0.2	0.73	0.3	0.75	0.25	0.42
	1.1	3.88	1.2	3.58	1.7	3.03	1.3	1.65	1.3	2.21	1.3	2.31	1.5	2.33	0.8	2.03	1.0	1.45	1.0	1.52	0.5	.82	.8	.85	0.5	.55
	2.6	4.21	2.2	3.72	3.4	3.55	2.3	1.72	2.3	2.43	2.3	2.45	3.5	2.45	2.8	2.38	3.0	1.65	2.0	1.72	1.5	1.05	1.8	1.00	1.0	.62
	4.2	4.26	4.0	3.93	5.1	4.02	4.3	1.52	4.3	2.29	4.3	2.31	5.5	2.24	4.8	2.47	5.0	1.34	4.0	1.50	2.5	1.02	2.8	.97	1.5	.62
	5.8	4.30	5.7	4.12	6.8	4.12	5.3	1.20	6.3	1.79	6.3	2.00	7.5	1.72	6.8	2.43	6.0	1.10	6.0	1.22	3.5	.92	3.8	.87	2.0	.59
	7.4	4.35	7.4	4.17	8.5	4.17	.....	.....	7.3	1.37	7.3	1.62	8.5	1.37	8.8	2.07	.....	.....	7.0	1.07	4.5	.74	4.8	.62	2.5	.50
	9.0	4.26	9.1	4.21	10.2	4.14	.....	.....	.....	.....	.....	.....	.....	.....	9.8	1.65	.....	.....	.....	.....	5.5	.65	.....	.....	3.0	.42
	10.5	4.09	10.8	4.17	11.9	4.09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	12.0	3.95	12.5	4.09	13.6	4.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	13.5	3.65	14.2	4.05	15.3	3.88	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14.3	3.53	15.9	3.91	17.0	3.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.0	3.01	16.7	3.70	17.3	2.84	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.5	2.52	17.5	2.43	17.5	2.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Bed of river, silt.

TABLE XIX.—*Velocities at regular intervals in vertical sections on Wallkill River, under ice, deduced from data in Table XVIII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	2.47	95	2.35	89	2.02	81	2.22	89	0.75	92	0.77	76	0.70	69	0.90	84	2.38	76	2.60	72	3.33	83	3.60	89	3.55	90
.15	2.81	108	2.81	107	2.32	93	2.53	101	.87	107	1.00	99	1.10	108	1.12	104	3.08	98	3.48	96	4.10	102	4.10	102	4.12	104
.25	3.06	117	3.15	119	2.57	103	2.74	110	.93	114	1.14	113	1.23	121	1.22	113	3.38	107	3.87	107	4.27	106	4.25	106	4.27	107
.35	3.13	120	3.22	122	2.70	109	2.88	115	.95	117	1.20	118	1.25	123	1.27	117	3.52	113	3.96	109	4.29	107	4.35	108	4.30	109
.45	3.07	118	3.12	118	2.74	110	2.89	116	.94	115	1.18	117	1.23	121	1.27	118	3.61	115	4.00	110	4.27	106	4.37	109	4.31	109
.55	2.88	111	2.94	111	2.75	111	2.82	113	.92	113	1.15	114	1.17	115	1.23	114	3.58	114	3.98	109	4.24	105	4.35	108	4.28	108
.65	2.67	102	2.69	102	2.72	110	2.66	107	.87	107	1.08	107	1.06	105	1.16	108	3.48	111	3.90	107	4.20	104	4.28	106	4.18	105
.75	2.41	92	2.42	92	2.60	105	2.42	97	.78	96	.99	98	.94	93	1.05	98	3.27	104	3.80	105	4.12	103	4.18	104	3.99	101
.85	2.06	79	2.06	78	2.38	96	2.15	86	.65	80	.88	87	.82	81	88	82	2.90	93	3.65	100	3.96	99	3.90	97	3.74	94
.95	1.50	58	1.64	62	2.05	82	1.63	66	.48	59	.72	71	.65	64	67	62	2.13	69	3.10	85	3.40	85	2.85	71	2.90	73
Mean	2.61	100	2.64	100	2.48	100	2.49	100	0.81	100	1.01	100	1.01	100	1.08	100	3.13	100	3.63	100	4.02	100	4.02	100	3.96	100

Depth in parts of total.[a]	Jan. 23.		Jan. 23.		Jan. 23.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	3.82	97	3.20	85	2.94	79	1.30	85	1.94	93	1.78	83	1.81	87	1.91	85	1.15	80	1.18	83	0.78	92	0.68	80	0.36	71
.15	4.17	106	3.80	98	3.60	96	1.53	100	2.24	108	2.26	106	2.28	109	2.21	99	1.44	101	1.56	110	.90	106	.87	103	.55	108
.25	4.30	109	4.02	103	4.05	109	1.68	110	2.40	115	2.42	113	2.44	117	2.36	105	1.58	111	1.70	120	1.04	122	.96	114	.61	120
.35	4.36	111	4.17	107	4.14	111	1.73	113	2.44	117	2.44	114	2.46	118	2.45	110	1.65	115	1.72	121	1.06	121	1.00	118	.62	121
.45	4.32	110	4.20	108	4.18	112	1.72	113	2.40	115	2.40	112	2.42	116	2.48	111	1.64	115	1.68	118	.99	116	.99	117	.61	119
.55	4.20	107	4.20	108	4.15	111	1.68	110	2.30	110	2.32	109	2.32	111	2.47	110	1.60	112	1.58	111	.93	109	.96	114	.58	114
.65	4.03	103	4.15	107	4.08	109	1.62	107	2.14	103	2.22	104	2.17	104	2.44	109	1.52	107	1.45	102	.85	100	.90	107	.55	108
.75	3.78	96	4.07	105	3.88	104	1.52	100	1.95	94	2.10	98	1.96	94	2.33	104	1.40	99	1.30	92	.76	90	.83	98	.49	96
.85	3.45	88	3.86	99	3.48	93	1.34	88	1.69	81	1.89	89	1.69	81	2.08	93	1.23	87	1.12	79	.66	78	.71	84	.42	82
.95	2.86	73	3.10	80	2.84	76	1.12	74	1.33	64	1.53	72	1.32	63	1.64	74	1.04	73	.90	64	.56	66	.55	65	.31	61
Mean	3.93	100	3.89	100	3.73	100	1.52	100	2.08	100	2.14	100	2.09	100	2.24	100	1.42	100	1.42	100	0.85	100	0.84	100	0.51	100

[a] The lower surface of the ice is zero depth.

TABLE XX.—*Velocities in vertical sections under ice on Esopus Creek.*[a]

Date	Jan. 9		Feb. 20		Feb. 28		Dec. 4		Dec. 4		Jan. 9		Jan. 9		Feb. 20	
Point of measurement	80.		80.		40.		90.		160.		90.		100.		90.	
Gage heights	6.55.		5.38.		9.14.		5.28.		5.28.		6.55.		6.55.		5.38.	
Total depth	6.8.		5.8.		6.3.		6.85.		5.05.		8.1.		6.1.		6.6.	
Thickness of ice	0.2.		0.1.		0.3.		0.05.		0.05.		0.1.		0.1.		0.2.	
Depth of water	6.6.		5.7.		6.0.		6.8.		5.0.		8.0.		6.0.		6.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	1.25	0.3	0.67	0.5	2.56	0.5	0.72	0.5	0.97	0.3	1.10	0.3	0.97	0.2	0.75
	1.3	1.50	1.2	.97	1.5	3.01	1.5	.85	1.5	1.07	1.3	1.35	1.3	1.27	0.9	.97
	2.3	1.52	2.2	.91	2.5	2.99	2.5	1.05	2.5	1.07	2.3	1.40	2.3	1.32	1.9	1.02
	3.3	1.50	3.2	.90	3.5	2.90	3.5	1.10	3.0	1.07	3.3	1.37	3.3	1.30	2.9	.95
	4.3	1.42	4.2	.87	4.5	2.29	4.1	1.09	3.5	1.07	4.3	1.32	4.3	1.25	3.9	.85
	5.3	1.32	5.2	.66	5.5	1.65	4.5	1.00	4.5	.62	5.3	1.17	5.5	1.02	4.9	.72
	6.1	1.10					5.6	.82			6.3	.90			5.9	.57
							6.3	.50			7.5	.60				

[a] Bed of river 40 to 80 is bowlders, 90 to 100 silt.

TABLE XXI.—*Velocities at regular intervals in vertical sections on Esopus Creek under ice, deduced from data in Table XX.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Jan. 9.		Feb. 20.		Feb. 28.		Dec. 4.		Dec. 4.		Jan. 9.		Jan. 9.		Feb. 20.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	1.26	91	0.67	81	2.40	98	0.67	75	0.93	98	1.14	99	0.97	81	0.73	88
.15	1.45	105	.85	102	2.75	107	.82	93	1.00	105	1.34	116	1.18	98	.93	112
.25	1.52	109	.94	113	3.00	116	.94	106	1.05	111	1.40	121	1.30	108	.99	119
.35	1.53	110	.95	114	3.08	119	1.03	116	1.07	113	1.40	122	1.33	111	1.01	122
.45	1.51	109	.93	112	3.02	117	1.09	122	1.08	114	1.36	118	1.32	110	.96	115
.55	1.49	107	.91	110	2.88	112	1.10	122	1.08	114	1.30	113	1.30	108	.90	108
.65	1.44	105	.88	106	2.70	105	1.05	118	1.05	111	1.19	103	1.27	106	.83	100
.75	1.37	99	.83	100	2.45	95	.92	102	.96	101	1.03	89	1.23	102	.75	91
.85	1.26	91	.75	91	2.07	80	.77	86	.78	82	.83	72	1.14	95	.66	80
.95	1.02	74	.59	71	1.45	56	.53	60	.50	51	.54	47	.97	81	.54	65
Mean	1.385	100	.83	100	2.58	100	.89	100	.95	100	1.15	100	1.20	100	.83	100

[a] The lower surface of the ice is zero depth.

TABLE XXII.—*Velocities in vertical sections under ice on Rondout Creek.*[a]

Date	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
Point of measurement	80.		90.		80.		90.		92.		92.		80.		40.	
Gage height	6.80.		6.80.		7.00.		7.00.		8.13.		8.43.		8.13.		8.13.	
Total depth	6.2.		6.6.		6.5.		7.0.		7.7.		8.0.		7.9.		6.4.	
Thickness of ice	0.1.		0.2.		0.2.		0.2.		1.5.		1.4.		1.5.		1.0.	
Depth of water	6.1.		6.4.		6.3.		6.8.		6.2.		6.6.		6.4.		5.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.62	0.3	0.55	0.8	1.05	0.8	1.07	0.3	0.92	0.3	1.70	0.3	1.40	0.4	1.30
	1.4	.73	1.3	.70	1.8	1.32	2.3	1.27	1.5	1.47	1.1	1.91	0.9	1.63	0.9	1.55
	2.4	.77	2.3	.65	2.8	1.47	3.3	1.27	2.5	1.59	2.1	2.00	1.9	1.67	1.9	1.67
	3.4	.71	3.3	.61	3.8	1.40	4.3	1.15	3.5	1.52	3.1	1.98	2.9	1.67	2.9	1.65
	4.5	.62	4.4	.55	4.8	1.35	5.3	1.10	4.6	1.25	4.1	1.73	3.9	1.60	3.9	1.57
	5.6	.51	5.9	.45	5.8	1.07	6.3	1.07	5.7	.82	5.1	1.32	4.9	1.42	4.9	1.32
											6.1	.85	5.9	1.15		

[a] Bed of creek is rock, with some bowlders from 0 to 40 and broken rock from 0.5 to 1 foot in diameter the remainder of width.

TABLE XXIII.—*Velocities at regular intervals in vertical sections on Rondout Creek under ice, deduced from data in Table XXII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	0.61	93	0.55	95	0.85	69	0.96	84	0.95	74	1.60	98	1.40	93	1.23	81
.15	.68	104	.65	112	1.09	88	1.12	98	1.30	101	1.90	116	1.62	107	1.50	99
.25	.75	114	.68	117	1.27	102	1.23	108	1.52	118	1.98	121	1.67	110	1.62	107
.35	.76	116	.67	116	1.40	113	1.27	112	1.58	122	2.02	123	1.68	111	1.67	111
.45	.75	114	.64	111	1.47	119	1.27	112	1.57	121	2.02	123	1.67	111	1.67	111
.55	.72	110	.61	106	1.46	118	1.25	110	1.53	118	1.87	114	1.64	109	1.65	109
.65	.67	102	.57	99	1.41	113	1.20	105	1.44	112	1.67	102	1.57	104	1.60	106
.75	.62	94	.53	91	1.31	106	1.12	99	1.27	99	1.42	86	1.46	97	1.54	102
.85	.55	84	.48	83	1.18	95	1.04	91	1.03	80	1.13	69	1.32	87	1.42	94
.95	.45	69	.40	70	.96	77	.92	81	.71	55	.79	48	1.07	71	1.20	80
Mean	.66	100	.58	100	1.24	100	1.14	100	1.29	100	1.64	100	1.51	100	1.51	100

[a] The lower surface of the ice is zero depth.

TABLE XXIV.—*Velocities in vertical sections under ice on Catskill Creek.*[a]

Date	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
Station	23.		23.		30.		40.		60.	
Gage height	4.50.		4.96.		4.60.		4.70.		4.80.	
Total depth	4.1.		4.7.		4.5.		5.8.		4.7.	
Thickness of ice	.7.		.5.		1.		1.2.		1.5.	
Depth of water	3.4.		4.2.		3.5.		4.6.		3.2.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.4	1.37	0.3	1.50	0.3	1.42	0.3	2.31	0.3	1.55
	.9	1.57	.7	1.94	.5	1.84	.7	2.41	.7	1.77
	1.4	1.57	1.2	1.96	1.0	2	1.1	2.44	1.2	1.77
	1.9	1.49	1.7	1.89	1.5	2.03	1.0	2.47	1.7	1.61
	2.4	1.16	2.2	1.79	2.0	1.91	2.1	2.44	2.2	1.35
	2.9	1.0	2.7	1.62	2.5	1.74	2.6	2.38	2.7	1.02
			3.2	1.37	3.0	1.55	3.1	2.31		
			3.7	1.07			3.6	2.14		
							4.1	1.89		

[a] Bed of stream rock ledge from 0 to 55, with gravel and silt over remainder of bed.

TABLE XXV.—*Velocities at regular intervals in vertical sections on Catskill Creek under ice, deduced from data in Table XXIV.*

[Velocities in feet per second.]

Depth in feet.	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	1.24	94	1.45	92	1.21	69	2.30	101	1.38	97
.15	1.42	108	1.82	115	1.85	106	2.42	106	1.68	117
.25	1.55	117	1.95	123	1.98	113	2.46	108	1.76	122
.35	1.60	121	1.91	121	2.04	117	2.47	108	1.78	124
.45	1.56	118	1.86	118	2.03	116	2.44	107	1.71	120
.55	1.48	112	1.75	111	1.95	111	2.40	105	1.58	111
.65	1.34	102	1.60	101	1.85	106	2.32	102	1.43	100
.75	1.19	90	1.42	90	1.72	98	2.20	97	1.22	85
.85	1.01	77	1.19	75	1.55	89	2.04	89	1.01	70
.95	.81	61	.85	54	1.32	75	1.75	77	.75	54
Mean	1.32	100	1.58	100	1.75	100	2.28	100	1.43	100

The data contained in Tables XIX and XX have been rearranged and combined in Table XXVI. The mean of the 26 vertical velocity curves taken on the Wallkill is shown in the column headed "Mean." The 26 curves are then separated according to the depth of water under ice at the point whence the observations were taken. In two observations the depth of water was less than 5 feet; in thirteen it was from 5 to 10 feet, and in 11 it was from 10 to 20 feet.

To bring out graphically the form of the vertical velocity curve under ice the data in Table XXVI have been plotted in fig. 5, where the solid line represents the mean of the 26 vertical velocity curves taken in the Wallkill. It will be noted that a decided drag occurs at the surface as well as at the bottom of this mean curve; that the maximum velocity occurs at a point about 0.35 of the depth, and that the mean velocity in the vertical occurs at about 0.13 and 0.73 of the depth. There will, in general, always be two points of mean velocity in vertical velocity curves taken under ice.

The results shown in the three last columns in Table XXVI are also plotted in fig. 5, and show the effect of the variation in depth upon the form of the curve. It will be seen that the curves drag more at shallow depths, the curve for depths under 5 feet being more concave than the others, the curve representing the measurements when the water was from 5 to 10 feet in depth being next most concave, while the curve representing the deepest measurement is flattest. This seems reasonable, and would probably hold true in all rivers.

It is frequently desirable to measure the flow of the river when frozen over. This can best be done by taking a large number of point measurements, as represented in fig. 4, but this is a slow process, so that it is important to know at what point the measurement of velocity can be made which will represent the mean velocity in the vertical section.

It will be seen from the four curves in fig. 5 that measurements made at 0.13 and 0.73 of the total depth measured from the bottom of the ice will represent in general the mean velocity in a vertical on a stream with the same general character as the Wallkill. The variation, however, between the curves representing different depths is greater at these two points than at points six hundredths and two-thirds of the depth. At these two points the curves almost coincide. The variation between the various curves was less—in fact within limits only one-half as great—at two-thirds depth as at six-hundredths depth. This shows that in these curves the limit of error is least when measurements are made at two-thirds depth and a coefficient is applied to determine the mean velocity. The mean curve shows a velocity of 105 per cent of the mean at two-thirds depth, so that it would appear that the most accurate method of determining the velocity under ice by observation at one point in the vertical would be to hold the meter at two-thirds depth and apply a coefficient of 0.95 to the observed velocity at that point. This would give a better result than measuring directly the velocity at 0.13 or 0.73 of the depth. In Table XXVII is shown the means of all the curves in the Esopus, Rondout, and Wallkill. These have been plotted in fig. 6. The variation of these three curves is not large, showing that the curve as

plotted represents fairly well the typical velocity curve of rivers of this character under ice cover. In Table XXVIII the results shown in all the preceding tables, for ice cover, including Wallkill, Esopus, Rondout, and Catskill, have been combined according to depth of

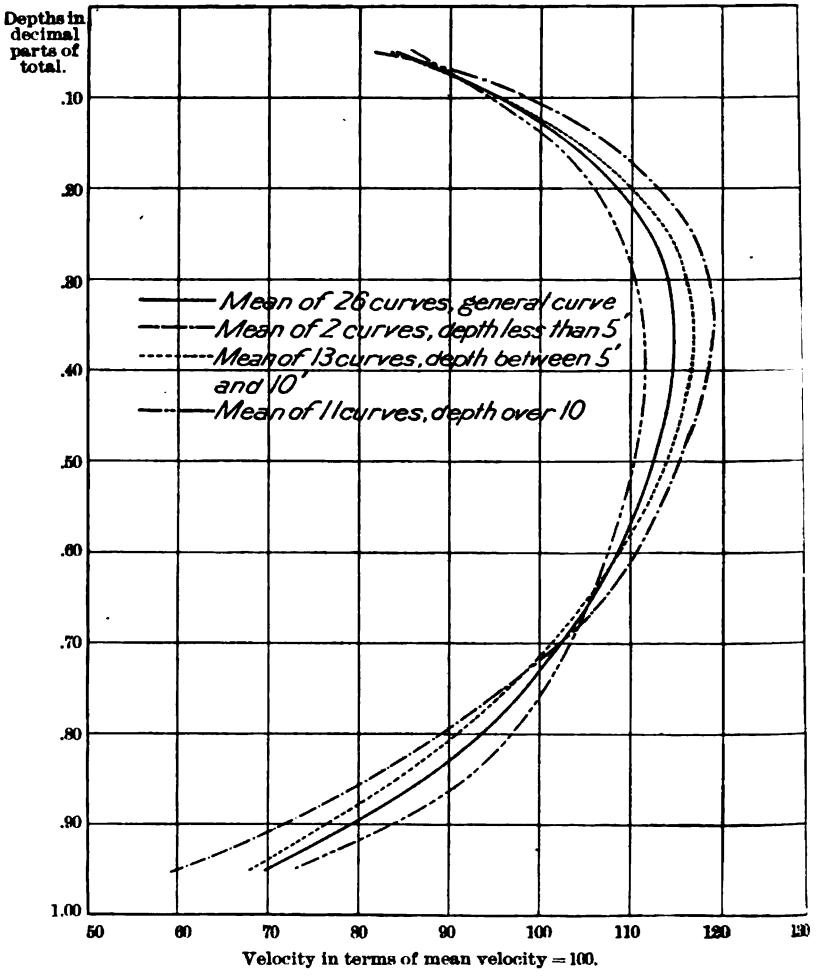


FIG. 5.—Mean vertical velocity curves on Wallkill River, with ice cover, showing the effect upon the curve of variation in depth of water.

NOTE.—The solid line is the mean of 26 vertical velocity curves at all depths; the dot-dash line the mean of two vertical velocity curves at depths less than 5 feet; the dotted line the mean of 13 vertical velocity curves at depths between 5 and 10 feet, and the dash-two-dot lines the mean of 11 vertical velocity curves at depths greater than 10 feet.

water under the ice, and have been plotted in fig. 7, together with the mean of all 47 curves. The form of these curves does not differ materially from those for the Wallkill, plotted in fig. 5. The point at which these curves fall closest together is, however, somewhat higher, at 0.6 depth. To a single measurement made at 0.6 depth a

coefficient of 0.92 should be applied to obtain the mean velocity in the vertical section, while the coefficient 0.95 should be applied to a single measurement made at two-thirds depth, as in the case of the Wallkill, shown in fig. 5.

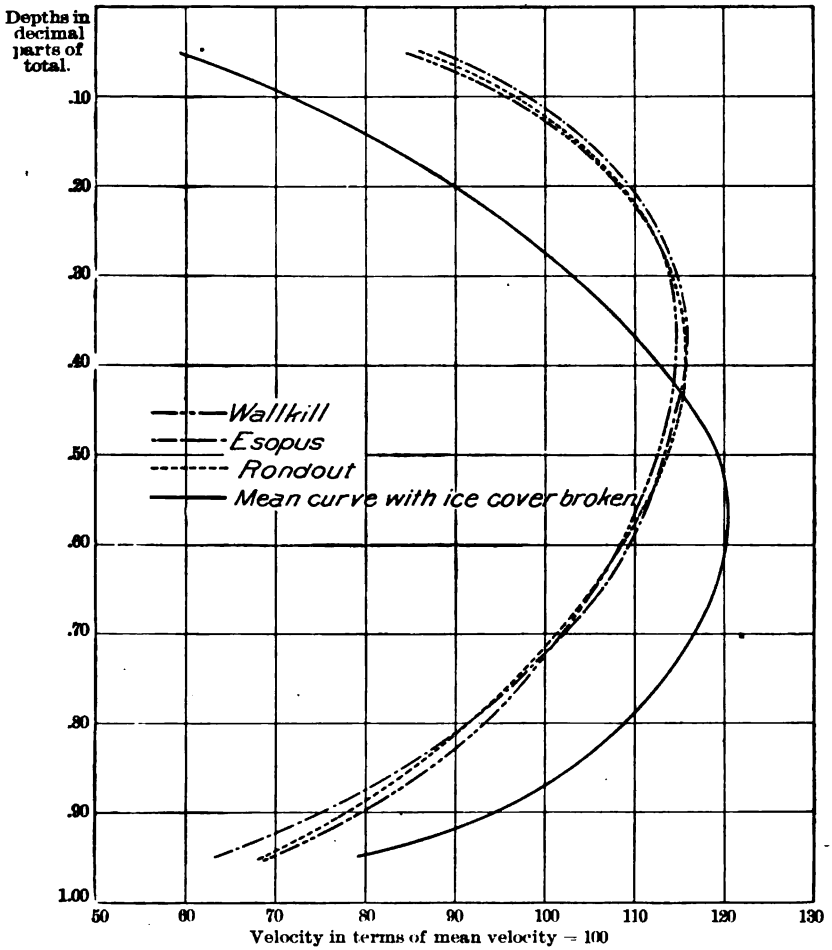


FIG. 6.—Mean vertical velocity curves on Esopus and Rondout creeks and Wallkill River, under ice cover, showing the comparatively slight variation in vertical velocity curves of rivers of this character.

NOTE.—The solid line shows the mean vertical velocity curve on the Wallkill and Rondout with the ice broken and tilted, and shows the decided drag caused by the increased friction at the surface.

There are many engineers who prefer to measure the velocity at mid-depth, and apply a coefficient to obtain the mean velocity in the vertical section. The observations recorded in Table XXVII show that the proper coefficient to apply is 0.88. Observations upon the flow of water under ice cover on the Upper Mississippi were made by

A. O. Powell, assistant engineer, under the direction of Col. Chas. J. Allen, Corps of Engineers, U. S. Army, in 1882 and 1890, and the pub-

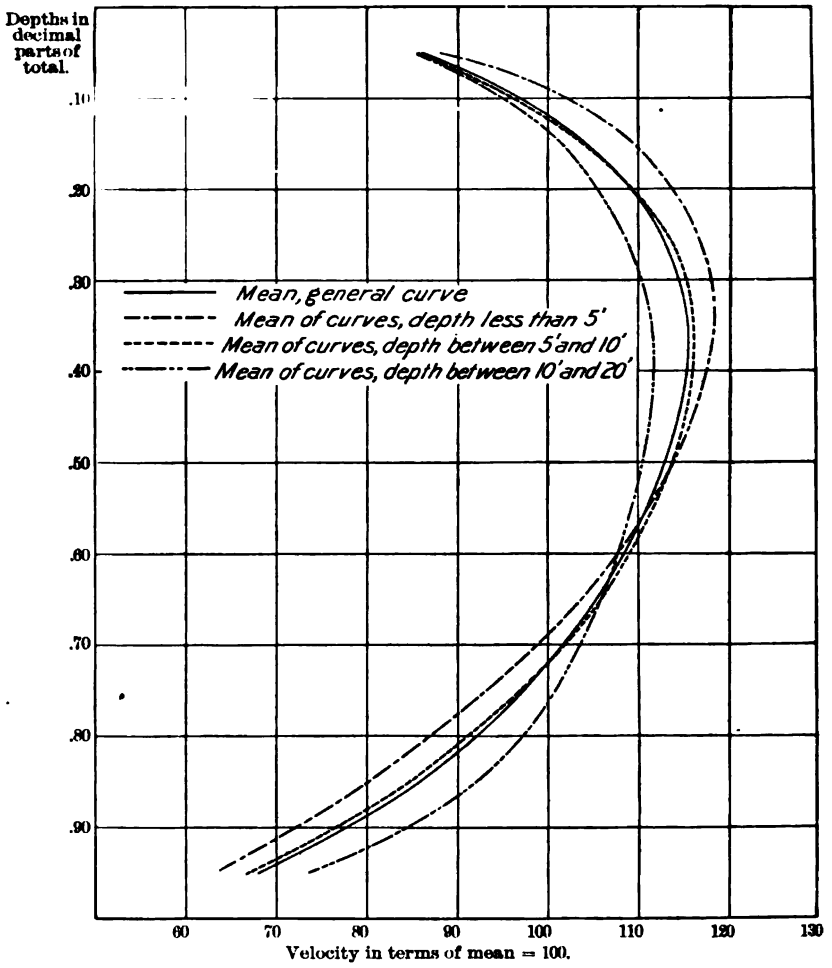


FIG. 7.—Comparison of curves for various depths of water under ice cover with the mean of all curves taken under ice.

NOTE.—The solid line is the mean curve and represents 47 vertical velocity curves. The dash-dot line is the mean of 7 curves with depths of water under ice of less than 5 feet. The dotted line is the mean of 29 vertical velocity curves with depths of water under ice ranging from 5 to 10 feet, and the dash-two-dot line is the mean of 11 vertical velocity curves for a depth of water under ice ranging from 10 to 20 feet.

lished results[a] show that this coefficient varied from 0.87380 to 0.88057.[b]

[a] Ann. Rept. Chief of Engineers, U. S. Army, Part III, 1890.

[b] Owing to the inaccuracies in observations of this kind, it does not seem to the author justifiable to carry the coefficient beyond the second place of decimals. The results obtained in the streams in New York agree with those in the Mississippi to the second place of decimals.

TABLE XXVI.—*Mean vertical velocity curve on Wallkill River and curves separated according to depths of water.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves	26.	2.	13.	11.
		Depth of water under ice.		
Depth below bottom of ice.	Mean.	Less than 5 feet.	Between 5 and 10 feet.	Between 10 and 20 feet.
0.05	84.0	81.5	83.2	85.5
.15	103.0	107.5	103.7	101.5
.25	112.0	117.0	114.0	108.6
.35	114.8	119.0	116.8	111.5
.45	114.0	117.0	115.7	111.4
.55	110.8	113.5	111.8	109.3
.65	105.8	107.5	105.5	105.9
.75	98.4	96.0	96.6	100.9
.85	87.5	81.0	84.5	92.1
.95	69.7	60.0	68.2	73.3
Mean	100.0	100.0	100.0	100.0

TABLE XXVII.—*Mean vertical velocity curves for Esopus, Rondout, and Wallkill, based upon a mean of 100.*

Stream	Esopus.	Rondout.	Wallkill.
Number of velocity curves	8.	8.	26.
Depth below bottom of ice.	Mean.	Mean.	Mean.
0.05	88.2	85.9	84.0
.15	104.7	103.1	103.0
.25	112.9	112.1	112.0
.35	115.9	115.5	114.8
.45	114.6	115.2	114.0
.55	111.8	111.7	110.8
.65	106.8	105.4	105.8
.75	97.4	96.8	98.4
.85	84.6	85.4	87.5
.95	63.1	68.9	69.7
Mean	100.0	100.0	100.0

TABLE XXVIII.—*Mean velocity curves upon Wallkill, Esopus, Rondout, and Catskill for various depths.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves.	7.	29.	11.	47.
Depth below bottom of ice.	Depth of water under ice.			
	Less than 5 feet.	5 to 10 feet.	10 to 20 feet.	Mean of all curves.
0.05	88.0	85.3	85.5	85.8
.15	109.6	103.8	101.5	104.1
.25	116.7	113.2	108.6	112.6
.35	118.4	116.2	111.5	115.5
.45	116.1	115.3	111.4	114.5
.55	111.0	111.8	109.3	111.1
.65	103.7	105.8	105.9	105.5
.75	93.2	96.9	100.9	97.3
.85	80.3	84.8	92.1	85.8
.95	63.0	66.9	73.3	67.8
Mean	100.0	100.0	100.0	100.0

FLOW OF RIVERS UNDER ICE, BROKEN AND TILTED COVER.

A few vertical velocity curves were taken on the Wallkill and Rondout when the ice on the river was broken and more or less tilted. No general law can be determined for such conditions, as the impeding power of the ice varies between wide limits. It is interesting, however, to note in a general way the effect of the ice. The drag at the surface is greatly increased and the curve is changed considerably in form. In Tables XXIX to XXXII will be found the results of the measurements, while in Table XXXIII is the summary of these results. The mean curve, as shown in Table XXXIII, is plotted in fig. 8, together with the mean curves when the ice covering was smooth. It will be seen from this diagram that the point of maximum velocity is 0.55 of the depth, much lower than with smooth ice; that the surface velocity is much less, and that the bottom velocity is greater. This curve would without doubt vary greatly at different times, depending upon the condition of the ice, so that measurement at any point for the determination of the mean velocity would not be advisable. Point measurements at frequent intervals would be necessary in order to obtain reliable results. It is not considered that the results show any decided law of relation between velocities at various depths, but the general form of the curve is characteristic in conditions similar to those under which these were taken.

TABLE XXIX.—*Velocities in vertical section on Wallkill River under ice broken and tilted.*

Date	Dec. 19.		Dec. 19.		Dec. 19.		Dec. 19.		Jan. 23.	
Point of measurement	115.		95.		85.		75.		30.	
Gage height	13.70.		13.70.		13.70.		13.70.		17.33.	
Total depth	18.0.		16.0¼.		15.6¼.		14.5.		14.4.	
Thickness of ice	4.0.		0.0¼.		0.0¼.		1.0.		1.4.	
Depth of water	14.0.		16.0.		15.6.		13.5.		13.0.	
	Depth.	Velocity.	Depth.	Velocity	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	0.30	1.5	2.73	1.1	2.52	1.0	1.52	1.0	1.72
	1.5	1.27	3.5	3.30	3.1	3.08	3.0	2.50	2.5	1.96
	3.5	2.33	5.5	3.48	5.1	3.48	5.0	2.94	4.5	2.26
	5.5	2.71	7.5	3.84	7.1	3.91	7.0	3.03	6.5	2.56
	7.5	2.99	9.5	4.12	9.1	3.95	9.0	3.13	8.5	2.64
	9.5	2.94	11.5	3.93	11.1	3.86	11.0	2.88	10.5	2.24
	11.5	2.64	13.5	3.60	13.1	3.50	13.0	2.45	12.5	1.67
	13.5	1.94	15.5	2.61	15.1	2.64	.....	.....	.....	.....

TABLE XXX.—*Velocities at regular intervals in vertical section on Wallkill River under ice broken and tilted, deduced from Table XXIX.*

Depth in parts of total.	Dec. 19.		Dec. 19.		Dec. 19.		Dec. 19.		Jan. 23.	
	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.05	1.10	45	2.35	68	2.40	71	1.40	54	1.68	77
.15	1.94	80	3.00	86	2.95	87	1.94	74	1.88	86
.25	2.41	99	3.35	97	3.33	98	2.60	99	2.07	94
.35	2.70	111	3.65	105	3.62	106	2.87	109	2.26	103
.45	2.90	119	3.90	112	3.86	113	3.04	115	2.45	111
.55	3.00	123	4.10	118	3.95	116	3.11	118	2.62	119
.65	2.94	120	4.07	117	3.90	115	3.08	117	2.62	119
.75	2.80	115	3.88	112	3.76	111	2.98	113	2.44	111
.85	2.55	104	3.60	103	3.42	101	2.78	106	2.15	98
.95	2.05	84	2.85	82	2.80	82	2.50	95	1.80	82
Mean	2.44	100	3.48	100	3.40	100	2.63	100	2.20	100

TABLE XXXI.—*Velocities in vertical sections on Rondout Creek at Rosendale under ice broken and tilted.*

Date	Dec. 6.		Jan. 14.		Jan. 14.		Jan. 14.	
Point of measurement	50.		40.		50.		60.	
Gage height	6.80.		7.00.		7.00.		7.00.	
Total depth	5.6.		4.8.		6.4.		6.4.	
Thickness of ice	0.2.		0.8.		0.4.		0.4.	
Depth of water	5.4.		4.0.		6.0.		6.0.	
	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.
	0.3	0.21	0.5	0.35	0.5	0.72	0.5	0.55
	1.3	.54	1.5	.75	1.5	.82	1.5	.87
	2.8	.55	2.5	.97	2.5	.90	2.5	1.17
	3.8	.57	3.5	.85	3.5	.90	3.5	1.15
	4.9	.36	.....	.....	4.5	.87	4.5	1.10
	.....	.....	.....	.....	5.5	.72	5.5	.85

TABLE XXXII.—*Velocities at regular intervals in vertical section on Rondout Creek under ice broken and tilted, deduced from Table XXXI.*

Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.25	53	0.24	34	0.67	81	0.48	51
.46	99	.40	57	.76	92	.68	72
.54	115	.55	79	.82	100	.87	93
.57	122	.70	100	.88	107	1.06	112
.57	122	.85	121	.90	110	1.19	127
.56	120	.95	136	.91	111	1.19	126
.55	117	.97	139	.90	109	1.14	121
.50	107	.95	135	.88	107	1.06	113
.43	92	.88	126	.82	100	.96	102
.25	53	.51	73	.69	83	78	83
.468	100	.70	100	.823	100	.941	100

TABLE XXXIII.—*Summary of curves on Wallkill and Rondout, under ice broken and tilted.*

Stream	Wallkill.	Rondout.	
Number of velocity curves	5.	4.	9.
Depth of water below bottom of ice.	13 to 16 ft. River bed: Silt.	4 to 6 ft. River bed: Bowlders and gravel.	Mean.
0.05	63.0	54.8	59.3
.15	82.6	80.0	81.4
.25	97.4	96.8	97.1
.35	106.8	110.2	108.3
.45	114.0	120.0	116.7
.55	118.8	123.2	120.8
.65	117.6	121.5	119.3
.75	112.4	115.5	113.8
.85	102.4	105.0	103.6
.95	85.0	73.0	79.7
Mean	100.0	100.0	100.0

QUALITY OF RIVER WATER.

A study of the turbidity, color, alkalinity, and hardness of these streams has been made in conjunction with the discharge measurements. It is thought that the information derived from such determinations will be of value to engineers investigating the future supply of New York City.

TURBIDITY AND COLOR.

Water in its ideal condition is perfectly clear and limpid, and has a slightly blue color. Filtered water, distilled water, and many spring waters approach closely to the ideal water. Most river waters are, however, either colored by contact with peat, muck, or decaying vegetation, or are turbid by reason of mud or silt carried in suspension. Muddy waters are often spoken of as colored waters, and in a sense this is correct where the mud consists of clays or other materials having distinct colors, but for convenience of classification it is better to refer to such waters as turbid waters, and to limit the term "colored waters" to those containing in solution vegetable matters which color them.

It has been observed that highly colored waters are usually free from turbidity, and vice versa, this being due to the fact that colored waters usually flow from drainage areas underlain by hard rocks not easily disintegrated, or from regions where the soils are firm or sandy, and especially from swamps. On such areas there is but little material that would be washed from the river banks and held in suspension, while the coloring material is present in the greatest abundance. In many parts of the United States shales or other soft materials

form the underlying beds. These readily disintegrate and form clay soils that are readily washed by hard rains. Waters from such areas are usually turbid and very highly colored.

Turbidity and color are principally important in their effect upon the appearance of water, whereas the other impurities discussed in this paper have absolutely no effect upon the appearance, and can be found only by their chemical action.

TURBIDITY.

The turbidity of water is a subject of great importance to the sanitary engineer. In questions of water supply, turbidity is often the important feature in the selection of a source of town supply; the number of days upon which the turbidity is above a certain fixed standard is also important, in that it may determine the size of reservoir required to store clear water sufficient to tide over the time of greatest turbidity, or for the sedimentation of suspended matters in the reservoir water. The importance of this subject varies with the part of the country studied, the waters in the New England States and New York being comparatively clear, while in the Southern Atlantic States and in the Ohio and Mississippi valleys high turbidities are the rule.

In the Northeast the terms "very slight, "slight," "distinct," and "decided" have been used by analysts to express the amount of suspended matter present. These degrees of turbidity have been estimated by the appearance of the sample to the eye when viewed toward the light. As the importance of these analyses has been more appreciated, particularly in connection with the purification of waters and the extended studies upon waters of high turbidity, it has been found that a more definite scale was necessary in order that proper comparisons of waters from various sources might be made.

In the filtration of water the engineer desires to know the amount of coagulant necessary to properly clarify the water, and it has been found that the turbidity gives a reliable index of the quantity of coagulant required. The object of the more recent studies has been, therefore, to express it numerically on some scale, referred to some standard, which can be easily reproduced and will be permanent.

There has been considerable difference of opinion as to the proper standard for turbidity comparisons, and some confusion has resulted. It is important that any standard selected should be applicable to both field and laboratory practice, and that observations made by different methods should be readily comparable.

The United States Geological Survey has had occasion, from time to time, to make observations of turbidity of rivers of which discharge measurements were made. Realizing the importance of a uniform standard for turbidity, the Survey has cooperated with Mr. Allen

Hazen and Mr. George C. Whipple in order that such a standard might be adopted. Mr. Hazen and Mr. Whipple have made joint investigations and studies, and have recommended the standard given below. This will be used in the future by the Survey, and it is hoped may be adopted generally throughout the United States.

PROPOSED TURBIDITY STANDARD.[a]

The standard of turbidity shall be a water which contains 100 parts of silica per million in such a state of fineness that a bright platinum wire 1 millimeter in diameter can just be seen when the center of the wire is 100 millimeters below the surface of the water and the eye of the observer is 1.2 meters above the wire, the observation being made in the middle of the day, in the open air, but not in sunlight, and in a vessel so large that the sides do not shut out the light so as to influence the results. The turbidity of such water shall be 100.

The turbidity of waters more turbid than the standard shall be computed as follows: The ratio of the turbidity of the water to 100 shall be as the extended volume is to the original volume, when the water is diluted with a clear water until the mixture is of standard turbidity.

The turbidities of waters lower than the standard should be computed as follows: The ratio of the turbidity of the water to 100 shall be as the ratio of the original volume of water of standard turbidity is to the extended volume when such water is diluted with a clear water until its turbidity is equal to that of the water under examination.

This standard can be used in both field and laboratory. In the field the wire method will be carried out as at present, except for a new graduation, while in the laboratory the methods of dilution and comparison now in use for the silicia standard will be used.

METHOD OF APPLICATION TO THE PLATINUM-WIRE PROCESS.

A rod with a platinum wire inserted in it at a fixed point and projecting from it at a right angle will be used as at present. The graduation shall be as follows: The graduation mark of 100 shall be placed on the head at a distance of 100 millimeters from the center of the wire. Other graduations will be made, based on the best obtainable data, in such a way that when a water is diluted the readings will decrease in the same proportion as the percentage of the original water in the mixture. Such a rod, having the graduation shown in the table below, shall be known as the United States Geological Survey turbidity rod of 1902. When this rod is immersed in water the visibility of the projecting platinum wire at the depth from the surface shown in the second column will determine the degree of turbidity, as indicated in the first column.

[a] From a letter signed by Messrs. Allen Hazen and George C. Whipple.

Graduation of rod.

Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.	Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.
	Mm.			*Mm.*	
7	1095	0.023	70	138.0	0.184
8	971	.026	75	130.0	.196
9	873	.029	80	122.0	.208
10	794	.032	85	116.0	.219
11	729	.035	90	110.0	.230
12	674	.038	95	105.0	.242
13	627	.041	100	100.0	.254
14	587	.043	110	93.0	.273
15	551	.046	120	86.0	.295
16	520	.049	130	81.0	.314
17	493	.052	140	76.0	.334
18	468	.054	150	72.0	.35
19	446	.057	160	68.7	.37
20	426	.060	180	62.4	.41
22	391	.065	200	57.4	.44
24	361	.070	250	49.1	.52
26	336	.076	300	43.2	.59
28	314	.081	350	38.8	.65
30	296	.086	400	35.4	.72
35	257	.099	500	30.9	.82
40	228	.111	600	27.7	.92
45	205	.124	800	23.4	1.09
50	187	.136	1000	20.9	1.21
55	171	.148	1500	17.1	1.49
60	158	.160	2000	14.8	1.72
65	147	.172	3000	12.1	2.10

This table is compiled from observations made at Cincinnati, St. Louis, New Orleans, Pittsburg, Brooklyn, Philadelphia, and Boston, for records of which we are indebted to several observers. The values of the turbidities by the reciprocal scale are included in the table as a matter of convenience, but they do not form a part of the standard.

This graduation is subject to revision whenever additional data shall make it necessary, and revised rods shall be designated by the same name, but with the year of revision substituted for 1902. The revisions shall have as their basis the one hundred mark, 100 millimeters from the wire.

Near the end of the rod, at a distance of 1.2 meters from the platinum wire, a wire ring shall be placed directly above the wire, through

0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Housatonic

which the observer will look, the object of the ring being to control the distance from the wire to the eye.

When the turbidity is greater than 500 the water should be diluted before the observation is made. When the turbidity is below 7 this method can not be used, and comparison should be made with the silica standard properly diluted in bottles or tubes.[a]

The number obtained by dividing the weight of suspended matter in parts per million by the turbidity as obtained above shall be called the coefficient of fineness. If greater than unity, it indicates that the matter in suspension in the water is coarser than the standard; if less than unity, that it is finer than the standard.

This standard is proposed with the idea of combining the best features of the platinum-wire and silica methods of measuring turbidities as commonly used, and of avoiding, as far as possible, the objections to each.

The wire method is most convenient as a field method. With the reciprocal scale, which until now has been used, it is open to the serious objection that the readings are not proportional to the amount of turbidity-producing matter in the water.

The silica standard is free from this objection and is more convenient as a laboratory method, but is not well adapted to field use, and is open to the objection that it is possible that the value may be changed by variations in the fineness of the silica particles composing the standard.

The standard now proposed is intended to overcome the above-mentioned defect in the platinum-wire method with the reciprocal scale, and at the same time to put a control on the value of the silica standard. Applying it in one way or the other, it is adapted to both field and laboratory use, and the results obtained should check substantially.

METHOD OF MAKING OBSERVATIONS.

The method of making the observations by means of the platinum wire is as follows: Take a stick of wood about 5 feet long and five-eighths of an inch square, more or less, and insert a platinum wire at a point about 1 inch from the end, so that the wire will be at right angles to the stick and project at least 1 inch. The wire should be 0.04 inch or 1 millimeter in diameter; the stick is then graduated, the lines for the various turbidities being at distances from the wire shown in the table on page 2.

Observations of turbidity are taken by putting this stick into the water under examination as far as the wire can be seen; the turbidity is then read from the scale. This is most conveniently accomplished by having a second or smaller stick placed in front of the first, the end of which is brought to the water line when the wire can just be

[a] Described by Whipple and Jackson in Technology Quarterly, Vol. XII, No. 4, December, 1899.

seen. Upon removing the two together the position of the smaller stick on the scale gives the turbidity.

Observations are to be taken in all cases in open air, as too high results are obtained under a roof, even with very good light; and they should preferably be taken in the middle of the day and not in direct sunlight. In case the sun is shining the observer can stand so that his shadow covers the water immediately about the stick and wire. The observations are taken with the eye of the observer at the ring before mentioned, 1.2 meters from the wire, although some variation in this does not materially influence the result. The wire should be kept bright and clean. In case it is lost, a clean bright pin can be used until another wire can be obtained. When the surface of the water in the stream is agitated by currents, waves, etc., or in case the depth is not sufficient to give the required immersion, or if for any reason observations can not be well taken from the bank, a pail or tub may be filled with water and the turbidity observations taken in it. In many cases this procedure is preferable to measurement in a stream, but the observation must be taken immediately upon filling the vessel. The diameter of the vessel should be equal to at least twice the depth at which the wire is immersed, as otherwise the results of the reading will be affected.

When the turbidity of the water is above 500, that is, in case the wire can be seen through less than 1 inch of water, the results obtained by direct measurement are not accurate. Such water should be diluted by 1, 2, or 4 volumes of clear water in the pail or tub, and thoroughly mixed.

The turbidity is taken as above described, and multiplied by the ratio that the total volume of water bears to the water in the mixture. Clear water can be obtained from a well or any other source obviously clear, or nearly so.

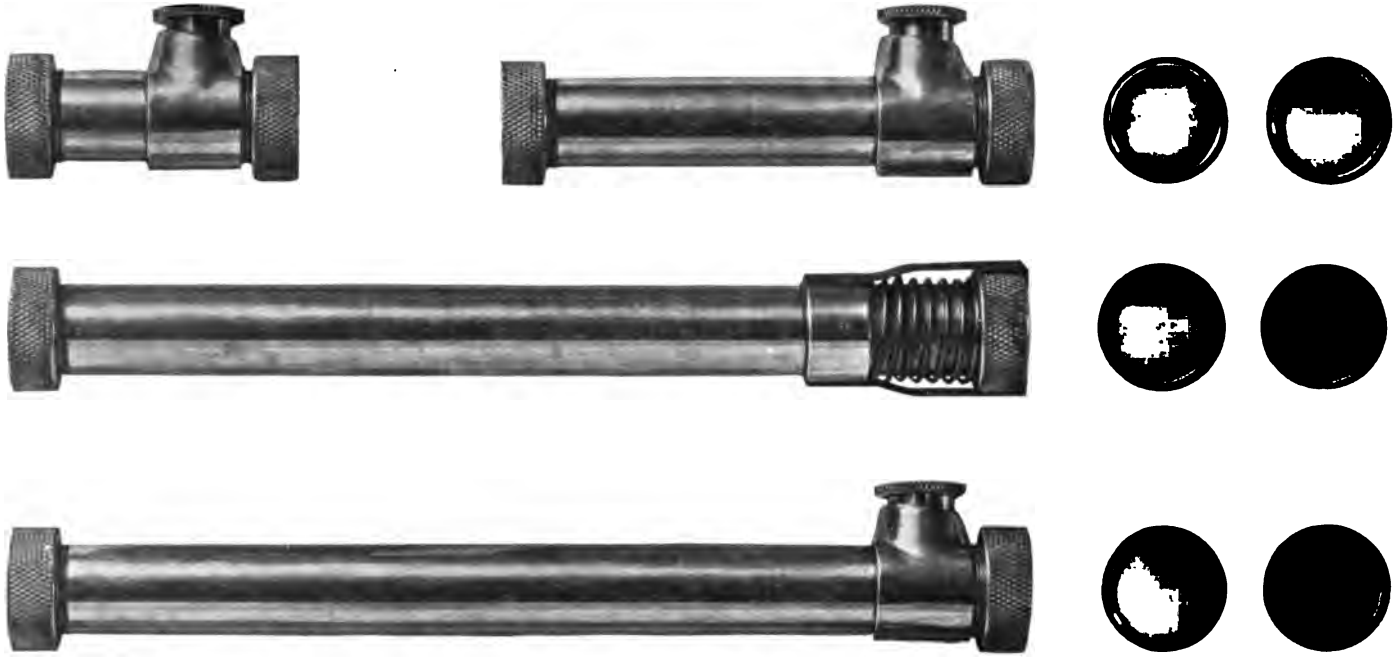
The statement of turbidity in such cases should contain memoranda that the observations were taken in this way, and should give the amount of dilution.

If waters have a turbidity less than 7 direct reading can not be used, and indirect methods must be resorted to.

The "wire method" has been described first in this paper, as it is best suited to field work. Besides this method, there are two others that have commended themselves to practical use. First, the use of standards of comparison; second, the diaphanometer.[a]

In the determinations of turbidity of waters in rivers considered in this paper, the turbidities were in general too low for accurate measurements by the wire method, and as the samples had to be shipped to the laboratory for other determinations, the turbidity was found by comparison with standards. These standards were made up from dia-

[a] These are both laboratory methods, and have been described by Mr. George C. Whipple and Daniel D. Jackson, in the Technology Quarterly, Vol. XII, No. 4, December, 1899.



TUBES AND DISKS FOR MEASURING IN THE FIELD THE COLOR OF RIVER WATER.

tomaceous earth thoroughly washed and ignited to remove the organic matter. The earth is then washed in hydrochloric acid and rinsed with water, after which it is pulverized. One-half grain is added to 500 c. c. of distilled water and thoroughly agitated. This stock mixture contains 1 grain of pure silica per liter, or 1,000 parts per 1,000,000, and when well shaken will always give the same turbidity, which is called a standard 1,000. For waters of low turbidities, like those found in New York State, standards are made by diluting the stock mixture with distilled water in measured proportions and comparing the collected samples with the various standards in gallon bottles, while with higher turbidities smaller quantities of the standards are placed in 100 c. c. Nessler tubes, with which the samples in like tubes are compared. This is a laboratory method, and is more precise than the wire method of making determination of turbidity, but requires that samples be collected and shipped to the laboratory.

In order that some idea of the meaning of the various standards may be obtained, the following table is inserted:

Table showing meaning of various numbers on silica scale.

Silica standard.	Destriptive term.
0	None.
1–2	Very slight.
2–5	Slight.
5–20	Distinct.
Above 20	Decided.

COLOR.

The platinum-cobalt method of measuring color, as devised by Allen Hazen, is generally considered the standard.

A standard solution which has a color of 500 shall be made by dissolving 1.246 grams potassium-platinic chloride[a] ($PtCl_4,2KCl$), containing 0.5 gram platinum, and 1 gram of crystallized cobalt chloride ($CoCl_2,6H_2O$), containing 0.25 gram of cobalt in water, with 100 cubic centimeters concentrated hydrochloric acid, and making up to 1 liter with distilled water. By diluting this solution standards shall be prepared having values of 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, and 70. The numbers correspond to the metallic platinum in the solutions in parts per million. These shall be kept in 100-cubic-centimeter Nessler jars of such diameter that the liquid shall have a depth between 20 and 25 centimeters and shall be protected from dust. The

[a] Potassium-platinous chloride is a salt that is often substituted by dealers in place of the potassium-platinic chloride. It is sometimes incorrectly labeled. The platinous salt has a reddish color while the platinic salt has a yellow color.

color of a sample shall be observed by filling a similar tube with water and comparing it with the standards. The observation shall be made by looking vertically downward through the tubes upon a white surface placed at such an angle that light is reflected upward through the column of liquid. The reading shall be recorded to the nearest unit. Waters that have a color darker than 70 shall be diluted before making the comparison, in order that no difficulties may be encountered in matching the hues. Water containing matter in suspension shall be filtered until no visible turbidity remains. If the suspended matter is coarse, filter paper may be used for this purpose; if the suspended matter is fine, the use of the Berkfeld filter is recommended, but it must be thoroughly washed each time before using. The use of a Pasteur filter is to be avoided, as it exerts a decolorizing action.

The determinations of color upon the streams considered in this paper, and given on the following pages, were made by the above laboratory method. For the sake of completeness, however, the field method of making determinations of color will be described.

It is impracticable to carry the standard tubes above described into the field for observations, and yet field observations are of great convenience and value to the sanitary engineer, and in general to the investigations of the United States Geological Survey.

Standard disks of colored glass have been prepared by Mr. Allen Hazen, in cooperation with the Survey, as standards for measuring color of water in the field (Pl. X). These disks have been rated by Mr. George C. Whipple to correspond with the platinum-cobalt standard. The color is measured by balancing the color of the water in a metallic tube with glass ends against the colors of glass disks of known value. The number on each disk represents the corresponding color of a water. This is not a new standard, but a new application of an old standard. The glass disks are rated to correspond with the platinum-cobalt color standard. The process bears the same relation to the usual laboratory process that an aneroid barometer bears to a mercurial barometer. The metallic tubes and glass standards are more portable and better adapted to field use than the Nessler tubes and color solutions previously used.

Color standards.—The standards are disks of amber-colored glass mounted with aluminum. Each disk carries two numbers. One number is over 100, and is a serial number for the purpose of identification. The other number is less than 100, and shows the color value of the disks; that is to say, the color of each disk is equal to the color of a solution of the designated number of parts per million of platinum with the required amount of cobalt to match the hue when seen in a depth of 200 millimeters.

Each apparatus has a series of glass disks of varying values, so that waters within a reasonable range can be matched by the disks. When a water comes between two disks its value can be estimated

between them by judgment. Two or more disks can be used, one behind the other, in which case their combined value is the sum of the individual values. By combining the disks of a series in different ways a considerable number of values can be produced, allowing the closer matching of many waters.

Filling the tubes.—The tube, having an aluminum stopper, is to be filled with water, the color of which is to be determined. Rinse the tube once or twice by filling and emptying it. The second tube, having the clips to hold the glass disks, is made much like the one holding the water to facilitate comparison. Theoretically this tube should be filled with distilled water. Practically it makes very little difference whether it is filled with distilled water or empty. Use distilled water when it is convenient to do so, and when distilled water of unquestionable quality is at hand; otherwise wipe the inside of the tube dry to prevent fogging of the glass ends, and proceed with the tube empty.

Holding the tubes.—Hold the tubes at such a distance from the eye that the sides of the tubes just can not be seen. This occurs when the near end of the tube is 8 or 9 inches from the eye. Hold the tubes at such an angle that both can be seen at once with one eye. Good results can not be obtained in any other way. Let the tubes change places once or twice, as sometimes the light on the right and left is not quite equal.

Background.—There should be a clear white background with a strong illumination. The best results can not be obtained with either too little or too much light. In a gray day look at the sky near the horizon and away from the sun. In a bright day look at a piece of white paper or tile, upon which a strong light falls. The white surface may be vertical and the tubes held horizontally, or the tubes may be held at an angle directed downward toward a horizontal surface, as may be most convenient. Good results can not be obtained by artificial light.

Turbid water.—The colors of very turbid waters can not be measured in this way. Slight turbidities do not interfere seriously with the results. Waters too turbid for direct observations should be filtered through thick filter paper before being tested, and in case the turbid matter is fine and in large amount even this method may fail. The turbidity of water should be taken as far as possible in connection with color observations, except in cases where it is obvious from inspection that there is practically no turbidity.

Highly colored waters.—Some waters will be found having a higher color than can be matched by the standards. In general, waters with colors above 100 should not be matched in 200-millimeter tubes, and the results with waters having colors below 80 will be considerably more accurate than with more highly colored ones. Two procedures are possible with waters having higher colors—namely, to dilute with dis-

tilled water before measuring the color or to use shorter tubes. The latter procedure is the more convenient, but both are equally accurate. To measure the color with short tubes, put the highly colored water in a tube of one-half the usual length and match as usual. It is not necessary to have a short standard holder. The 200-millimeter tube can be used. After the water is matched the result is multiplied by 2. In case the color is too high to be read in a 100-millimeter tube it can be put in a 50-millimeter tube, and the result multiplied by 4. When dilution is used the highly colored water is mixed with one or more volumes of distilled water, the color matched, and the result multiplied by a corresponding factor. The tube itself can be used for measuring the colored water and the distilled water, and the mixing can be done in a tumbler or any convenient clean vessel.

Cleaning the tubes.—The tubes should always be kept clean and the glass ends protected. All the ends are removable for the purpose of cleaning, and should not be screwed on too tightly. They should be water-tight when only screwed up loosely, and if screwed on hard they may stick so as to come off with difficulty.

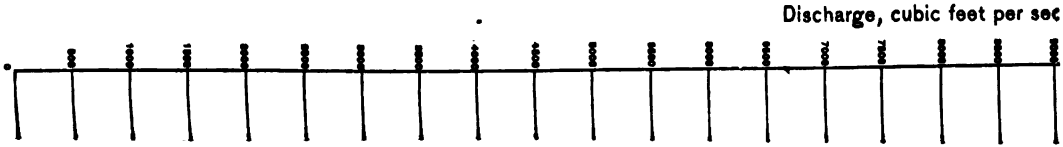
ALKALINITY.

The alkalinity of water is practically a measure of the carbonates and bicarbonates present. The determination is made as follows: Put 100 c. c. of the sample into a 6-inch porcelain evaporating dish. Add two or three drops of a 0.1 per cent aqueous solution of methyl-orange. If the water is alkaline, this will impart to it a faint yellowish brown color. Then from a burette graduated in tenths of a cubic centimeter run in a fiftieth-normal solution of sulphuric acid until the color of the water changes to a faint pink. The acid must be added in small portions (only one drop at a time as the end point is reached) and the water stirred with a glass rod after each addition. The number of cubic centimeters of fiftieth-normal acid required, when multiplied by ten, gives the alkalinity of the water expressed in equivalent parts per million of calcium carbonate. That is, if 1.8 c. c. is required to cause the color of the indicator to change from brown to red, then the alkalinity of the water is 18 parts per million. Inasmuch as it is necessary to add a certain amount of fiftieth-normal acid to 100 c. c. of water which has no alkalinity in order to produce the typical color change, the reading obtained must be corrected for this amount. This correction for the indicator varies with different individuals, but it seldom exceeds 0.3 c. c.

Other indicators, such as lacmoid or erythrosine, may be used in place of methyl-orange, and in certain instances their use is to be preferred, but for general field work methyl-orange is most convenient.

PERMANENT HARDNESS.

The Clark's soap method has been used in the examinations of river waters given in the following tables. This method gives reliable


Discharge, cubic feet per sec
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000

results for waters as soft as those under consideration, but for the hard waters of the Central States Hehner's acid method will perhaps give more reliable and uniform results.

Results of determinations of hardness obtained by various observers are frequently very discrepant, and it is not uncommon to have results reported by chemists which are worthless on account of faulty methods. It is hoped that the determinations of hardness may be made upon a more uniform basis throughout the country, so that the results may be comparable.

In the following tables are given the results of the observations upon turbidity, color, alkalinity, and hardness, together with the discharge of Esopus, Rondout, Wallkill, Catskill, Fishkill, Tenmile, and Housatonic:

Turbidity color, alkalinity, and hardness of streams.

CATSKILL CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 19	[a]2.62	6	1	58.0	.....	28
Aug. 27	[a]2.95	11	2	48.0	.....	77
Sept. 2	[a]3.00	7	2	53.0	.....	89
Sept. 8	[a]2.90	9	2	55.0	.....	66
Sept. 23	2.73	2	2	54.0	.....	39
Oct. 4	2.70	4	1	51.0	.....	36
Oct. 10	2.65	1	.....	53.0	53.0	31
Oct. 22	2.82	6	3	50.0	.....	51
Nov. 8	2.70	1	.....	49.0	50.0	36
Nov. 19	2.75	3	1	50.0	50.0	42
Dec. 9	3.30	2	.....	38.0	44.5	110
1902.						
Jan. 15	3.50	2	1	38.0	42.0	144
Feb. 27	4.90	22	11	25.0	26.0	400
Apr. 10	6.70	22	25	22.0	24.0	2,200
May 10	3.47	4	6	36.0	42.0	133
June 3	2.82	6	1	42.0	50.0	99
June 24	2.70	9	3	47.0	51.5	43
July 9	3.40	9	2	45.0	47.0	113
July 23	6.11	35	25	35.0	44.5	1,602
Aug. 2	5.36	33	12	42.0	49.0	1,005
Aug. 13	3.49	12	1	50.0	50.5	135
Aug. 27	2.74	11	4	56.0	52.0	394
Sept. 5	2.79	6	4	56.0	56.0	50

[a] Taken from gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 28	7.15	42	4	37.0	.....	620
Sept. 1	7.62	32	20	23.0	.....	980
Sept. 3	7.80	66	6	11.0	.....	1,126
Sept. 4	7.13	68	15	18.0	.....	602
Sept. 19	6.87	30	12	18.0	.....	430
Do	6.87	30	13	14.0	.....	430
Oct. 11	6.50	26	4	17.0	.....	185
Oct. 3	6.95	40	4	22.0	22.0	481
Oct. 15	7.65	26	8	22.0	[a] 21.0	1,001
Oct. 22	6.70	28	3	20.0	[a] 19.0	314
Oct. 31	6.50	24	4	24.0	[a] 24.0	185
Nov. 13	7.00	21	14	26.0	27.0	515
Nov. 16	6.60	26	5	20.0	26.0	249
Nov. 19	6.40	21	2	20.0	24.0	123
Nov. 22	6.35	23	3	19.0	25.0	92
Nov. 26	7.30	32	7	17.0	23.0	728
Nov. 29	6.80	31	3	21.0	24.0	380
Dec. 3	6.40	23	7	21.0	24.5	123
Dec. 6	6.80	21	3	19.0	23.5	28[illegible]
Dec. 10	9.80	32	65	19.0	25.0	1,70[illegible]
Dec. 11	9.50	38	([b])	13.0	20.0	2,65[illegible]
Dec. 12	8.50	34	19	12.0	17.5	1,7[illegible]
Dec. 15	16.70	80	([b])	13.0	18.0	12,3[illegible]
Dec. 16	11.00	48	75	11.0	20.0	4,2[illegible]
Dec. 25	7.25	13	7	14.0	26.0	5[illegible]
Dec. 30	12.20	32	60	10.0	20.0	5,5[illegible]
1902.						
Jan. 7	7.00	17	5	14.0	24.0	51[illegible]
Jan. 14	6.70	14	4	20.0	23.5	24[illegible]
Jan. 18	6.70	14	3	18.0	21.0	24[illegible]
Jan. 23	10.30	32	3	10.0	12.5	3,4[illegible]
Jan. 25	7.90	23	1	12.0	14.5	1,21[illegible]
Jan. 28	7.70	80	10	21.0	25.5	67[illegible]
Feb. 4	9.50	14	18	14.5	21.5	2,6[illegible]
Feb. 11	8.20	11	11	19.5	24.5	9[illegible]
Feb. 14	7.85	10	6	20.0	24.5	74
Feb. 27	10.45	22	30	13.0	15.9	2,0[illegible]

[a] Likely too low. [b] Bottle broken.

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Mar. 1	17.55	42	145	14.0	14.3	13,900
Mar. 2	14.00	40	120	14.5	13.5	7,900
Mar. 3	11.75	31	55	11.0	11.9	5,075
Mar. 4	9.90	21	30	9.5	12.0	3,043
Mar. 8	7.75	30	28	14.0	16.5	1,084
Mar. 9	12.70	35	48	12.5	15.0	6,120
Mar. 9	9.50	19	50	14.0	21.0	2,650
Mar. 10	10.00	23	80	12.5	19.5	3,150
Mar. 29	11.00	25	40	14.0	19.0	4,250
Apr. 8	7.65	21	15	13.0	17.0	1,000
Apr. 10	11.95	32	32	12.0	14.0	5,665
Apr. 24	6.90	14	4	18.0	22.0	447
Apr. 26	7.10	16	35	15.5	20.5	585
Apr. 30	9.30	25	28	13.5	19.0	2,470
May 26	6.90	12	8	23.0	24.5	447
May 28	7.10	14	21	23.0	24.5	585
June 5	6.45	14	18	27.0	28.0	156
June 6	6.40	13	7	23.0	25.0	163
June 18	6.50	13	10	28.0	30.0	185
June 19	6.30	13	14	32.0	32.5	75
June 22	7.20	12	20	25.0	31.2	656
June 28	7.55	21	24	20.5	24.7	920
July 3	6.80	31	30	21.5	22.8	380
July 19	6.30	15	2	27.0	30.5	75
July 21	8.65	40	95	21.0	22.0	1,885
July 22	9.75	35	105	15.0	19.5	2,890
July 23	8.60	45	35	13.0	17.0	1,840
July 26	9.85	45	45	15.0	24.0	2,991
July 31	7.35	30	14	14.0	24.0	765
Aug. 7	7.30	28	8	19.0	26.0	838
Aug. 13	6.80	17	2	18.0	23.0	380
Aug. 15	6.50	[illegible]	1	22.0	22.5	185
Aug. 20	6.40	20	2	24.0	28.0	123
Aug. 21	6.35	16	2	25.0	27.0	92
Aug. 25	6.25	11	5	23.0	24.5	60
Aug. 27	6.30	14	13	30.0	29.0	75
Aug. 30	6.35	12	5	26.0	27.5	92
Sept. 5	6.10	11	4	26.0	31.0	35

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Sept. 8	6.20	11	2	28.0	31.0	50
Sept. 11	6.50	14	6	23.0	24.5	185
Sept. 16	6.30	17	3	23.0	26.0	75
Sept. 17	6.20	17	3	23.0	28.0	50

ESOPUS CREEK.

1901.						
Aug. 25	7.67	52	35	17.5	([a])	1,200
Aug. 27	6.02	34	7	22.0		540
Aug. 29	5.72	28	3			430
Sept. 4	6.27	19	13	19.0		640
Sept. 21	4.78	11	3	23.0		198
Sept. 26	4.55	9	4	23.5		167
Oct. 3	5.25	16	6	18.0		295
Oct. 8	4.70	14	3	18.0		188
Oct. 17	6.30	14	10	14.0	15.0	650
Nov. 1	4.75	9	4	15.0	18.0	195
Nov. 14	4.75	9	4	21.0	22.0	195
Nov. 18	4.45	9	2	17.0	22.0	153
Dec. 4	5.30	10	6	16.0	20.5	223
Dec. 11	[b]11.40	45	38	10.0	16.0	1,721
Dec. 19	8.35	22	50	22.5	19.0	1,470
Dec. 30	12.10	25	80	11.0	17.0	3,723
1902.						
Jan. 9	6.50	15	15	13.0	21.0	514
Jan. 22	16.00	29	180	10.0	15.0	7,600
Feb. 7	6.80	16	20	15.0	19.5	628
Feb. 20	5.35	8	5	19.0	23.5	231
Mar. 1	20.40	48	180	11.0	16.5	12,600
Mar. 12	9.90	25	125	18.5	23.5	2,843
Apr. 10	13.25	22	35	9.0	13.5	5,021
Apr. 23	6.94	16	21	13.0	15.0	910
May 14	5.83	12	10	16.0	20.0	474
May 24	5.02	8	4	19.0	24.0	238
June 5	5.03	14	17	20.0	22.5	2,345
June 16	4.48	10	5	24.0	26.0	1,358
June 26	5.00	18	13	20.0	22.0	2,312

[a] From Aug. 25 to Oct. 8, hardness not determined.

[b] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

ESOPUS CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
July 9	5.80	20	12	16.0	27.5	4,504
July 16	5.13	10	10	18.0	27.5	2,688
July 24	8.11	35	15	15.0	28.5	1,348
July 30	7.65	23	8	14.0	24.0	1,155
Aug. 12	6.28	21	8	24.0	26.5	550
Aug. 21	4.94	14	6	23.0	25.5	191
Sept. 4	4.49	11	6	34.0	31.0	133

WALLKILL RIVER.

1901.						
Aug. 17	6.75	78	3	77.0	.....	565
Aug. 20	7.2	110	9	48.5	.....	794
Aug. 23	6.25	104	6	58.0	.....	321
Aug. 24	6.05	110	12	64.0	.....	232
Aug. 28	5.85	82	14	62.0	.....	165
Aug. 31	5.95	86	12	71.0	.....	196
Sept. 5	8.55	82	12	65.0	.....	1,503
Sept. 19	7.30	45	13	59.0	.....	814
Oct. 9	6.50	60	7	67,0	.....	440
Oct. 31	6.10	46	5	81.0	93.0	264
Nov. 9	5.94	28	4	92.0	105.0	202
Nov. 16	6.50	45	9	88.0	97.0	440
Dec. 11	[a] 11.50	60	45	43.0	50.0	2,480
Dec. 19	13.70	55	38	37.0	42.0	3,680
Dec. 30	20.20	35	45	24.0	26.0	8,190
1902.						
Jan. 13	8.05	33	15	74.0	83.0	717
Jan. 23	16.40	38	125	25.0	30.0	5,422
Feb. 10	7.78	21	14	67.0	76.0	596
Feb. 24	7.30	19	10	89.0	97.2	382
Mar. 10	16.40	31	160	26.0	31.0	5,422
Apr. 21	7.55	29	25	56.0	60.0	977
May 1	10.00	60	28	44.0	46.0	2,540
May 21	6.33	39	8	75.0	89.0	356
June 6	6.40	20	13	73.0	84.0	381
July 17	5.70	33	5	82.0	90.0	126
July 29	7.49	52	23	54.0	72.0	942

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

WALLKILL RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Aug. 6	7.98	68	25	62.0	71.0	1,150
Aug. 15	6.72	48	8	83.0	84.0	518
Aug. 28	5.86	24	5	88.0	89.0	169
Sept. 6	5.78	38	5	57.0	61.0	145

TENMILE RIVER.

1901.						
Sept. 12	5.90	13	2	121.0	.....	364
Oct. 26	5.00	12	4	134.0	142.0	166
Nov. 11	4.75	8	2	146.0	151.0	120
Nov. 22	4.80	8	2	147.0	154.0	129
Dec. 2	4.75	6	1	137.0	152.5	120
Dec. 17	8.41	25	12	79.0	86.0	1,120
Dec. 27	6.54	22	9	103.0	106.0	524
1902.						
Jan. 10	5.75	11	4	98.0	103.0	328
Feb. 4	6.30	13	11	90.0	104.0	460
Feb. 13	5.00	8	6	126.0	137.0	166
Mar. 3	[a] 10.41	21	36	60.0	61.1	[b] 2,100
Apr. 7	[a] 6.18	12	3	100.0	103.0	558
May 2	6.46	19	7	105.0	112.0	640
May 15	4.88	12	1	118.0	123.0	230
June 9	4.44	16	15	130.0	139.0	122
June 30	4.90	19	6	133.0	160.0	249
July 21	7.20	40	25	88.0	90.0	821
Aug. 4	4.69	11	3	129.0	141.0	1,848
Aug. 19	4.28	10	4	138.0	160.0	100
Sept. 2	3.95	10	4	139.0	155.0	63

FISHKILL CREEK.

1901.						
Aug. 21	[c] 4.45	39.0	2	88	.....	286
Aug. 31	[c] 4.57	24.0	4	85	.....	335
Sept. 4	[c] 4.42	24.0	6	88	.....	277
Oct. 8	3.90	13.0	3	82	93.0	113

[a] All readings on this and following dates made on new gage placed 0.33 foot higher than the old gage.

[b] Approximate.

[c] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Oct. 10	3.85	11.0	2	94	100.0	100
Oct. 17	4.50	36.0	4	72	[a]68.0	305
Oct. 25	4.05	16.0	2	88	[a]84.0	154
Oct. 31	4.00	12.0	3	87	89.0	140
Nov. 5	3.90	12.0	5	85	89.0	113
Nov. 8	3.95	11.0	4	85	92.0	500
Nov. 13	4.35	17.0	4	80	87.0	250
Nov. 15	4.05	21.0	4	78	109.0	154
Nov. 19	3.95	13.0	4	79	94.0	126
Nov. 23	3.90	8.0	4	83	89.0	113
Nov. 26	4.30	22.0	5	74	84.0	233
Dec. 17	6.10	29.0	12	45	47.0	926
Dec. 19	5.10	21.0	7	58	64.0	409
Dec. 24	4.55	11.0	5	71	78.0	224
Dec. 26	4.55	13.0	4	74	79.0	224
Dec. 31	7.30	24.0	12	33	39.0	1,682
1902.						
Jan. 2	5.65	15.0	7	52	60.0	673
Jan. 7	4.80	12.0	3	66	78.0	300
Jan. 9	4.65	11.0	2	70	81.0	[b]253
Jan. 14	5.00	5.0	3	79	83.0	[b]370
Jan. 16	4.35	6.0	5	79	85.0	[b]172
Jan. 21	4.15	6.0	3	82	85.0	[b]128
Jan. 28	4.90	30.0	25	52	55.5	[b]334
Jan. 30	4.95	9.0	4	63	77.0	[b]352
Feb. 4	5.50	13.0	7	53	60.0	[b]594
Feb. 7	5.20	11.0	6	72	82.0	640
Feb. 11	4.80	7.0	4	74	81.0	430
Feb. 18	4.40	5.0	6	80	86.0	268
Feb. 20	4.40	7.0	11	79	87.0	268
Mar. 7	5.20	11.0	14	48	60.0	640
Apr. 18	4.60	10.0	5	63	68.0	345
Apr. 22	4.30	9.5	4	70	72.0	233
Apr. 24	4.10	11.0	3	72	76.0	169
Apr. 29	4.00	13.0	3	79	82.0	140
May 15	3.90	11.0	4	74	85.0	113
May 20	3.80	11.0	3	76	85.0	88
May 22	3.70	13.0	2	79	85.0	66

[a] Likely too low. [b] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
May 28	4.55	34.0	5	70	80.0	405
June 6	3.50	11.0	3	79	81.0	115
June 10	3.80	19.0	4	79	85.0	175
June 16	3.50	14.0	5	84	90.0	115
June 19	3.50	16.0	5	86	91.0	115
July 5	3.60	15.0	4	81	90.0	135
July 8	3.50	20.0	2	83	85.0	115
July 11	3.40	14.0	3	86	86.0	95
July 16	3.10	10.0	2	89	94.0	55
Aug. 4	3.60	13.0	2	81	86.0	135
Aug. 6	3.40	11.0	3	82	89.0	95
Aug. 11	3.60	14.0	12	74	81.0	135
Aug. 13	3.60	17.0	2	74	81.0	135
Aug. 19	3.20	10.0	3	84	90.0	65
Aug. 21	3.10	7.0	2	84	86.0	55
Sept. 1	2.90	12.0	4	94	96.0	35
Sept. 2	2.80	12.0	5	93	96.0	30
Sept. 5	2.90	8.0	3	89	97.0	35
Sept. 9	3.00	9.0	3	85	89.0	40
Sept. 12	3.05	12.0	3	73	85.0	45
Sept. 15	3.20	12.0	2	77	87.0	65

HOUSATONIC RIVER.

1901.						
Oct. 29	4.05	19.0	3	108	103.0	935
Nov. 13	4.83	25.0	4	102	106.0	1,860
Nov. 23	4.10	21.0	5	100	105.0	980
Dec. 28	5.16	14.0	6	91	97.0	2,420
1902.						
Jan. 11	5.00	13.0	5	89	92.0	2,145
Feb. 14	[a] 8.30	20.0	5	96	103.0	8,000
Mar. 18	7.63	24.0	.....	53	60.0	8,277
May 3	6.10	20.0	11	78	86.0	4,459
June 22	4.70	24.0	4	89	92.0	1,530
June 23	4.50	18.0	3	92	94.0	1,177
June 25	4.30	14.0	3	93	95.0	1,070

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

HOUSATONIC RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
June 26	4.30	15.0	2	94	95.0	1,070
July 2	4.60	18.0	3	90	90.0	1,400
July 4	4.70	20.0	6	91	93.0	1,530
July 6	4.50	16.0	2	93	93.0	1,177
July 8	5.00	22.0	3	91	94.0	2,145
July 15	3.90	14.0	5	85	101.0	750
July 18	3.90	18.0	7	95	98.0	750
July 22	6.70	34.0	22	63	75.0	5,119
July 25	5.60	30.0	12	73	82.0	3,050
July 29	4.90	26.0	7	88	91.0	1,800
Aug. 1	4.80	35.0	4	88	94.0	1,650
Aug. 5	4.20	14.0	4	102	109.0	983
Aug. 8	4.50	14.0	2	102	107.0	1,177
Aug. 12	5.20	32.0	5	73	83.0	2,300
Aug. 15	4.50	31.0	3	85	86.0	1,177
Aug. 19	3.70	11.0	3	96	106.0	----
Aug. 22	3.90	11.0	2	96	99.0	750
Aug. 26	3.90	11.0	4	103	107.0	750
Aug. 29	3.90	10.0	3	96	104.0	750
Sept. 2	3.60	10.0	2	98	113.0	640
Sept. 5	3.60	9.0	1	104	110.0	640
Sept. 9	3.40	10.0	1	105	109.0	490
Sept. 12	3.90	13.0	2	97	104.0	750

Though the number of observations is not sufficient to give accurate curves, the results as shown in the tables have been plotted in Pls. IX, XI, XII, and XIII[a] and tentative curves drawn showing the relation of these qualities to the discharge of the stream. In the curves representing alkalinity and hardness the relation seems to be well marked. The diagrams show the relative hardness of the various streams, also ratio of decrease in hardness as the discharge increases. The regularity of the points enables one to prophesy with fair precision the alkalinity or hardness that might be expected at intermediate discharges. The turbidity and color are, as might be expected, far more irregular. It would not be expected that during a rapidly rising flood we should find the same turbidity as at the time of general high water. The

[a] Since the diagrams were plotted many more observations have been obtained and are included in these tables. The diagrams have not been changed, as they are only intended to be suggestive.

effect, too, of a local shower on one tributary may affect the quality of the water much more than the same increase of water from another tributary, so that in an exhaustive study of a large river the effect of floods on each tributary is important, and should be studied rather than the river as a whole. Most of the tributaries of the streams under consideration are short, and storms would usually cover a large part of the drainage basin.

It is not considered that results have been obtained that are final upon these points, so that their publication is in the nature of a progress report. Measurements are being continued, and it is hoped that better curves can be constructed later. The curves representing tur-

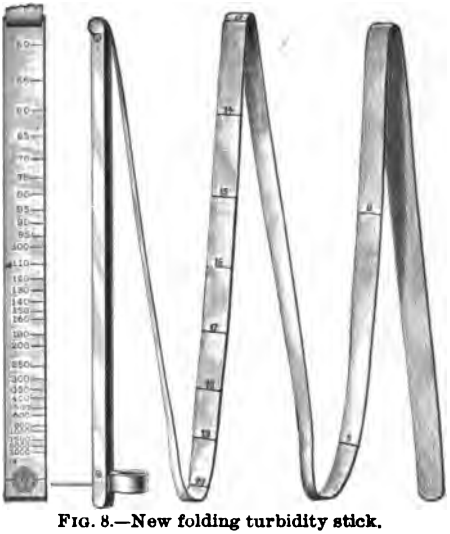


FIG. 8.—New folding turbidity stick.

bidity and color are merely suggestions. It was not intended that the color curves of the Catskill and Tenmile should turn so far to the left at the upper part.

GAGE HEIGHTS AND DISCHARGE MEASUREMENTS.

In the following tables are given the mean daily gage heights during the years 1901 and 1902 at the stations established upon the Catskill, Esopus, Rondout, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers.

Following these tables are records of current-meter discharge measurements on these streams. These observations and measurements are being continued.

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.55	2.92	2.8	2.7	2.65	17	3.85	2.4	2.82	3.02	2.77	5.0
2	.....	2.6	3.0	2.75	2.7	2.65	18	3.78	2.52	2.97	2.97	2.75	4.4
3	.....	2.55	3.22	2.7	2.65	2.65	19	4.35	2.62	2.97	2.9	2.75	4.0
4	2.75	2.4	3.27	2.7	2.67	3.3	20	3.58	2.67	2.82	2.85	2.75	3.85
5	2.9	2.4	3.05	2.67	2.67	3.3	21	3.17	2.75	2.8	2.82	2.75	3.9
6	3.3	2.5	2.92	2.67	2.65	3.32	22	2.67	3.05	2.8	2.8	2.75	4.0
7	3.6	3.35	2.87	2.62	2.7	3.32	23	2.95	3.22	2.77	2.8	2.7	4.0
8	3.63	3.05	2.9	2.65	2.7	3.3	24	3.0	3.45	2.72	2.8	2.7	4.07
9	3.35	2.87	2.87	2.6	2.65	3.35	25	3.02	3.55	2.67	2.8	2.7	3.45
10	3.07	2.8	2.82	2.65	2.65	5.35	26	2.82	3.2	2.65	2.8	2.7	3.4
11	3.53	2.77	2.8	2.6	2.65	4.62	27	2.7	2.95	2.65	2.75	2.65	3.4
12	3.45	2.65	2.75	2.6	2.67	4.45	28	2.7	2.8	2.7	2.75	2.65	3.5
13	3.23	2.55	2.77	2.65	2.8	3.95	29	2.72	2.7	2.8	2.75	2.65	3.85
14	3.0	2.5	2.72	2.8	3.02	6.95	30	2.65	2.65	2.82	2.7	2.65	4.5
15	2.85	2.5	2.7	3.1	2.85	12.8	31	2.6	2.6	.....	2.7	.....	4.4
16	2.9	2.5	2.75	3.15	2.82	5.6							

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1902

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	4.30	11.70	5.35	4.10	2.95	3.48	4.50	2.90	6.18	4.30	3.60
2	.....	5.05	9.68	5.88	3.95	2.88	3.28	5.58	2.83	5.63	4.15	3.63
3	.....	5.20	6.70	4.95	3.93	2.80	3.13	4.38	2.75	5.20	4.05	3.80
4	.....	4.45	6.80	4.88	3.88	2.83	3.10	4.13	2.73	4.80	3.95	4.18
5	4.40	4.40	6.35	4.90	3.83	2.88	3.08	3.85	2.73	4.60	3.90	4.00
6	4.20	4.40	5.40	4.65	3.78	2.88	4.45	4.45	2.70	4.53	3.83	4.00
7	4.05	4.30	4.10	4.40	3.73	2.85	4.20	4.20	2.73	4.40	3.77	3.98
8	4.80	4.25	4.10	4.60	3.70	2.90	3.48	3.98	2.78	4.23	3.73	3.80
9	3.70	4.20	4.30	11.65	3.60	2.80	3.80	3.80	2.90	4.05	3.65	3.70
10	3.55	4.25	5.20	8.25	3.50	2.75	3.65	3.65	3.68	3.90	3.55	4.05
11	3.40	4.40	5.75	6.98	3.40	2.70	3.60	3.55	3.55	3.98	3.50	4.40
12	3.30	4.50	9.10	6.48	3.30	2.65	3.55	3.55	3.28	5.08	3.55	4.13
13	3.30	4.70	9.20	5.50	3.28	2.78	2.95	3.45	3.40	4.60	3.63	4.00
14	3.30	4.95	7.50	4.95	3.23	2.75	2.80	3.15	3.58	4.25	3.53	4.00
15	3.20	3.10	5.45	4.78	3.20	2.70	2.80	3.20	3.35	4.15	3.50	3.95
16	3.30	3.20	7.40	4.58	3.05	2.75	2.75	3.15	3.18	4.25	3.40	4.53
17	3.20	3.40	9.43	4.35	3.00	2.90	2.70	3.05	3.05	3.93	3.40	6.35
18	3.00	3.50	6.85	4.25	2.95	2.88	2.65	2.93	2.95	3.83	3.33	5.43
19	2.90	3.60	4.15	4.20	2.90	2.78	2.70	3.05	2.98	3.80	3.30	5.00
20	2.90	3.80	4.50	4.20	2.95	2.85	4.40	3.10	3.25	3.83	3.28	4.80
21	3.10	3.80	4.00	4.13	2.95	2.80	7.25	3.03	3.48	3.73	3.30	6.65
22	9.85	3.80	4.55	4.10	2.83	2.80	6.50	2.98	3.58	3.73	3.20	8.48
23	5.90	3.50	5.58	4.03	2.78	2.80	6.53	2.93	3.18	3.60	3.20	6.70
24	4.80	3.20	5.48	3.95	2.90	2.78	6.18	2.83	3.10	3.63	3.15	5.13
25	4.40	3.40	5.05	3.90	2.95	2.70	7.08	2.75	3.25	3.60	3.20	4.85
26	4.03	3.50	4.93	3.80	2.85	2.68	7.85	2.70	3.58	3.50	3.30	6.65
27	3.85	4.83	4.83	3.83	3.10	2.65	4.05	2.70	4.35	3.55	3.85	4.35
28	3.58	9.15	5.03	3.73	3.33	2.60	4.20	2.73	[a]4.70	5.90	4.13	4.20
29	3.70	.....	5.73	3.95	3.25	2.80	4.40	2.85	9.95	5.30	3.80	4.13
30	4.25	.....	5.93	4.10	3.13	3.88	4.38	2.98	7.20	4.70	3.63	3.95
31	4.30	.....	5.43	.....	3.00	.....	4.25	3.08	.....	4.45	.....	3.85

[a] 12 o'clock midnight, 16.1.

Mean daily gage height of Esopus Creek, at Kingston, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1		3.97	6.47	4.52	4.62	4.6	17	4.05	4.37	5.0	4.47	4.3	10.55
2		3.95	6.3	4.62	4.52	4.52	18	4.05	4.54	5.27	4.42	4.37	9.05
3		3.9	6.67	4.7	4.35	4.77	19	4.6	4.5	5.07	4.6	4.52	8.1
4		4.95	6.27	4.52	4.37	5.45	20	4.15	4.77	5.35	4.77	4.5	8.0
5	4.3	3.95	5.8	4.42	4.55	4.62	21	4.1	5.95	5.17	4.77	4.47	7.75
6	4.35	3.7	5.57	4.3	4.47	4.67	22	3.9	6.62	4.77	4.67	4.52	7.2
7	4.3	3.95	5.42	4.47	4.57	4.72	23	4.05	5.92	4.92	4.67	4.45	6.85
8	4.4	7.0	5.02	4.57	4.47	4.65	24	4.0	7.35	4.77	4.62	4.52	6.7
9	4.4	5.72	5.17	4.5	4.32		25	3.9	7.67	4.5	4.62	4.62	6.5
10	4.25	5.17	4.95	4.52	4.32	5.6	26	3.97	6.52	4.37	4.52	4.6	6.35
11	4.25	5.05	5.02	4.47	4.45	11.5	27	3.92	6.02	4.5	4.42	4.57	6.25
12	4.3	4.87	4.87	4.4	4.57	9.72	28	3.85	5.87	4.72	4.45	4.77	6.0
13	4.3	4.72	4.9	4.5	4.6	7.35	29	3.72	5.72	4.45	4.57	5.45	7.55
14	4.2	4.6	4.87	4.52	4.45	8.12	30	4.2	5.45	4.42	4.47	4.52	11.65
15	3.95	4.42	4.72	4.57	4.37	21.37	31	4.25	5.22		4.6		9.45
16	4.2	4.42	4.75	4.65	4.43	15.2							

Mean daily gage height of Esopus Creek at Kingston, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.20	7.25	12.10	9.35	8.95	4.85	6.38	7.09	4.45	13.38	7.28	5.90
2	10.35	7.45	16.82	8.69	8.18	4.83	6.19	7.95	4.48	11.68	6.75	5.70
3	9.95	9.35	15.75	8.05	7.78	4.76	6.00	7.10	4.43	10.10	5.83	6.19
4	8.40	7.72	11.07	7.64	7.70	4.83	6.40	6.90	4.33	9.50	6.55	6.43
5	7.65	7.52	9.45	7.33	7.43	4.70	5.99	6.53	4.38	8.60	6.55	6.33
6	7.30	7.16	8.95	7.03	7.11	4.73	6.19	7.08	4.33	9.64	6.25	6.18
7	6.95	6.70	7.90	7.18	6.98	4.55	6.16	6.90	4.38	8.68	6.47	6.35
8	6.65	6.47	7.68	7.28	6.74	4.63	6.03	3.43	4.38	8.18	6.35	6.6[illegible]
9	6.50	6.14	8.85	13.10	6.55	4.63	5.80	6.18	4.38	7.85	6.13	6.45
10	6.40	6.25	9.20	13.86	6.40	4.68	5.58	5.88	7.68	7.40	6.00	6.90
11	6.35	5.94	9.05	11.60	6.23	4.58	5.50	5.83	6.00	7.15	7.85	6.35
12	5.88	5.88	9.80	10.22	6.10	4.45	5.34	6.25	5.49	9.10	7.95	6.55
13	6.00	5.77	11.85	9.41	5.96	4.53	5.15	5.73	5.53	8.47	5.85	6.35
14	5.93	5.60	11.82	8.78	5.88	4.58	5.05	5.58	6.18	8.00	5.78	6.40
15	5.60	5.58	9.98	8.25	5.70	4.40	4.98	5.38	5.85	7.60	5.73	6.43
16	5.58	5.53	9.33	7.90	5.70	4.46	4.99	5.30	5.53	7.33	5.63	6.65
17	5.59	5.63	[a]18.28	7.58	5.50	4.78	4.89	5.08	5.30	7.15	5.60	16.20
18	5.30	5.39	13.10	7.35	5.33	4.94	4.80	5.10	5.13	6.95	5.60	12.86
19	5.50	5.45	10.13	7.10	5.38	4.63	4.78	4.98	5.08	6.75	5.54	11.00
20	5.37	5.30	9.20	6.93	5.39	4.60	6.88	4.98	5.30	6.73	5.46	9.95
21	4.95	5.35	8.62	6.80	5.28	4.81	10.00	4.88	6.88	6.47	5.45	8.55
22	12.73	5.36	8.25	6.78	5.13	5.55	9.50	4.85	6.28	6.30	5.32	15.60
23	10.88	5.30	8.20	6.93	5.03	5.13	9.28	4.78	5.88	6.20	5.36	12.80
24	8.88	5.36	7.87	6.88	5.00	4.93	8.38	4.65	5.68	6.13	5.30	10.40
25	8.00	5.39	7.63	6.58	4.88	4.81	8.58	4.70	5.68	6.30	5.29	9.35
26	7.53	6.45	7.43	6.36	5.20	4.93	8.68	4.65	7.00	5.87	5.30	8.70
27	8.63	9.30	7.28	6.35	5.20	5.15	8.01	4.55	10.35	5.78	6.10	8.28
28	8.08	9.37	7.17	6.20	5.58	4.84	7.75	4.65	9.48	7.83	6.60	8.75
29	7.72		11.65	5.98	5.25	4.81	7.19	4.70	[b]22.43	8.35	6.10	9.10
30	7.82		12.55	9.81	5.03	7.10	7.68	4.60	17.35	7.75	5.88	8.97
31	7.48		10.45		5.03		7.35	4.63		7.50		8.05

[a] Highest water at 1.30 p. m., 25.25.

[b] Highest water at 1.30 p. m., 18.30.

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	7.57	7.62	7.26	6.5	6.55	17	6.3	6.5	6.67	7.1	6.55	8.95
2	.....	5.5	7.95	6.85	6.5	6.4	18	6.85	6.75	7.05	7.0	6.55	8.04
3	.....	6.3	7.8	6.95	6.5	6.5	19	6.55	7.0	6.85	6.9	6.55	7.77
4	.....	6.25	7.61	6.8	6.45	6.85	20	6.48	6.95	6.65	6.8	6.5	7.55
5	.....	6.17	7.42	6.7	6.4	6.87	21	6.47	8.75	6.55	6.72	6.4	7.55
6	.....	6.35	6.97	6.62	6.4	6.85	22	6.37	8.15	6.52	6.7	6.35	7.57
7	.....	9.75	6.87	6.55	6.4	6.92	23	6.4	7.5	6.47	6.7	6.4	7.95
8	6.5	7.35	6.77	6.55	6.4	7.0	24	6.35	9.0	6.42	6.6	6.5	7.75
9	6.4	6.92	6.67	6.52	6.4	7.2	25	6.35	9.4	6.4	6.6	7.6	7.22
10	6.25	6.62	6.6	6.45	6.4	9.2	26	6.3	8.1	6.35	6.6	7.25	7.12
11	6.2	7.17	6.6	6.42	6.37	9.25	27	6.47	7.47	6.32	6.6	6.97	7.0
12	6.25	7.42	6.65	6.42	6.45	8.22	28	6.42	7.15	6.3	6.65	6.87	7.35
13	6.3	6.87	6.72	6.5	6.95	7.75	29	6.37	6.95	7.05	6.5	6.8	9.1
14	6.33	6.55	6.57	7.25	6.8	8.97	30	6.67	7.42	7.41	6.5	6.8	12.12
15	6.3	6.50	6.5	7.72	6.62	16.75	31	6.72	6.72	.....	6.5	.....	10.0
16	6.38	6.52	6.62	7.37	6.6	10.6							

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.73	8.98	17.20	8.18	8.25	6.58	7.08	7.70	6.25	10.08	7.25	6.73
2	7.90	8.95	14.23	7.85	7.70	6.48	6.90	8.35	6.20	9.28	7.05	6.70
3	7.90	9.75	12.53	7.58	7.70	6.55	6.98	7.60	6.13	8.43	7.03	6.90
4	7.90	9.35	9.75	7.58	7.75	6.63	7.70	7.28	6.15	7.90	7.00	7.20
5	7.90	9.70	8.70	7.35	7.50	6.48	7.23	7.08	6.10	7.80	6.90	6.88
6	7.83	9.25	8.05	7.25	7.33	6.40	7.13	7.25	6.18	8.78	6.87	6.80
7	7.58	9.00	7.95	7.60	7.28	6.48	7.00	7.33	6.20	8.00	6.95	6.95
8	7.28	8.83	7.65	8.10	7.15	6.45	6.88	7.03	6.20	7.65	6.85	6.98
9	7.13	8.58	9.40	12.28	7.03	6.48	6.85	6.93	6.23	7.38	6.80	6.88
10	7.08	8.05	9.70	11.40	6.93	6.38	6.65	6.83	7.00	7.18	6.78	7.10
11	7.10	8.18	9.30	9.75	6.88	6.30	6.58	6.80	6.58	6.95	6.73	7.08
12	7.35	8.05	9.70	9.15	6.88	6.35	6.58	6.90	6.40	9.75	6.73	7.00
13	6.95	7.98	11.05	8.63	6.83	6.35	6.50	6.80	6.45	8.65	6.73	6.95
14	6.73	7.88	10.15	8.15	6.68	6.38	6.45	6.70	6.68	8.00	6.70	7.15
15	6.83	7.80	9.15	7.85	6.63	6.35	6.35	6.55	6.48	7.57	6.70	7.50
16	6.90	7.65	8.80	7.65	6.70	6.35	6.40	6.58	6.35	7.35	6.70	8.35
17	6.78	7.53	13.10	7.50	6.60	6.50	6.33	6.50	6.25	7.23	6.65	12.95
18	6.70	7.60	9.95	7.38	6.63	6.45	6.30	6.45	6.20	7.07	6.65	10.00
19	6.78	7.35	8.65	7.25	6.60	6.30	6.33	6.40	6.18	7.07	6.68	8.80
20	6.70	7.43	8.25	7.18	6.60	6.43	7.53	6.40	6.25	7.00	6.65	8.30
21	6.73	7.43	8.08	7.10	6.58	6.43	8.93	6.38	6.50	6.95	6.65	8.35
22	14.68	7.40	8.00	7.05	6.50	7.10	9.18	6.48	6.40	6.90	6.65	13.45
23	9.83	7.43	7.88	7.00	6.48	6.70	8.38	6.40	6.23	6.80	6.60	10.58
24	8.35	7.48	7.80	6.90	6.45	6.50	[a]9.94	6.40	6.25	6.80	6.60	9.55
25	7.85	7.55	7.63	6.88	6.40	6.40	10.34	6.33	6.45	6.80	6.55	8.50
26	7.68	8.23	7.45	6.98	6.80	6.43	8.95	6.30	9.40	6.73	6.70	8.10
27	8.95	10.68	7.38	6.95	6.88	6.50	8.23	6.28	9.75	6.63	6.75	8.87
28	7.75	12.10	7.33	6.83	7.20	6.43	7.80	6.25	8.68	9.38	6.90	7.45
29	8.00	.....	9.85	6.78	6.85	6.45	7.38	6.33	[b]14.09	8.60	6.88	7.27
30	8.18	.....	9.53	9.38	6.60	7.70	7.80	6.30	10.78	7.83	6.80	7.20
31	8.60	.....	8.63	.....	6.63	.....	7.33	6.30	.....	7.45	.....	7.20

[a] Highest water, 12.65, at 7 p. m.

[b] Highest water, 15.6, at 3 p. m.

Estimated diversion from Rondout Creek to Delaware and Hudson Canal, Rosendale, N. Y., 1902, in second-feet.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1				15.5	22.6		24.2	26.0		22.6	22.5	
2				17.7	15.0	25.2	23.8	25.6	25.3	22.4		
3				21.5	24.6	20.8	23.1		22.5	26.1	21.0	
4				22.0		11.6		23.8	24.3	25.8	23.5	
5				17.9	27.6	25.3	24.1	24.5	25.3		21.5	
6					23.1	19.5		22.5	25.8	22.2	23.3	
7				20.4	24.8	21.8	23.1	24.5		23.1	24.2	
8				20.2	24.3		22.7	23.8	25.0	22.4	24.8	
9				18.4	24.6	23.8	24.3	24.0	23.5	21.9		
10				14.3	24.5	35.9	25.3		24.3	22.8		
11				20.7		24.9	26.1	24.0	24.3	22.1		
12				19.2	24.3	33.8	21.8	24.5	25.1			
13					24.1	27.5		24.6	22.2	20.4		
14				25.4	25.0	23.6	25.3	26.0		20.6		
15				25.7	24.1		25.3	24.8	26.5	20.5		
16				24.2	24.5	22.3	24.2	24.5	25.6	19.5		
17				25.1	22.8	22.6	26.0		25.8	19.5		
18				26.1		24.3	25.1	25.5	23.3	19.7		
19				25.6	24.3	23.8	22.7	24.3	24.8			
20					24.6	23.9		23.8	22.0	21.3		
21				25.9	23.1	24.4	23.8	25.1		23.5		
22				26.7	23.6		25.6	25.6	24.3	21.0		
23			15.8	24.1	25.6	22.1	22.8	24.3	23.8	21.2		
24			11.4	23.3	24.3	20.1	20.6		24.0	23.0		
25			12.3	23.4		22.6	19.0	22.8	25.1	20.4		
26			15.3	22.8	21.1	22.8	22.8	22.2	22.8			
27			16.9		28.0	19.8		25.1	22.6	22.8		
28			16.4	27.1	26.5	22.6	25.6	22.5		23.8		
29				25.2	26.3		21.6	25.8	20.3	24.3		
30				25.8	20.7	26.7	23.6	23.0	22.1	23.0		
31			21.8		24.1		26.4			25.0		
Mean				22.5	24.0	23.7	23.8	24.3	24.0	22.2		

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1		6.10	9.20	7.45	6.00	6.25	17	6.37	6.75	7.05	7.50	6.25	13.10
2		5.90	9.85	7.25	6.00	6.05	18	7.15	9.25	7.62	7.27	6.05	13.65
3		5.97	9.75	7.15	6.00	6.00	19	7.98	11.15	7.65	7.15	6.15	13.75
4		6.00	9.35	7.00	6.00	6.20	20	7.20	10.15	7.45	6.95	6.35	12.95
5		6.45	8.55	6.95	6.05	6.35	21	6.50	10.25	7.30	6.70	7.30	11.70
6		6.45	8.35	6.85	6.10	6.65	22	6.35	10.25	7.10	6.45	8.10	10.70
7	7.27	12.05	8.05	6.65	6.00	6.60	23	6.25	10.15	6.95	6.32	8.65	10.45
8	7.23	11.25	7.70	6.47	5.95	7.30	24	6.05	9.70	6.82	6.30	8.35	10.15
9	6.93	9.30	7.47	6.35	5.85	10.00	25	6.00	14.30	6.65	6.20	8.10	9.55
10	6.65	9.15	7.45	6.30	5.75	12.30	26	6.00	12.00	6.50	6.12	7.45	9.00
11	6.53	9.10	7.25	6.30	5.65	11.70	27	5.85	11.25	6.35	6.10	6.95	9.25
12	7.33	8.05	7.05	6.20	5.95	10.30	28	5.85	10.60	6.35	6.10	6.85	9.70
13	7.60	7.70	7.15	6.20	6.40	10.05	29	5.85	9.90	6.65	6.10	6.65	11.80
14	7.15	7.15	6.95	6.35	7.00	10.60	30	5.80	9.15	7.25	6.10	6.45	19.35
15	6.85	7.40	6.65	7.50	6.90	13.30	31	5.95			6.50		19.20
16	6.55	7.10	6.75	7.85	6.55	12.85							

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	15.15	8.75	23.53	9.35	10.25	7.50	7.25	9.50	6.10	10.25	8.65	6.80
2	13.25	8.75	23.80	8.95	8.95	7.25	7.15	9.10	6.05	10.85	8.35	6.70
3	12.95	10.65	[a]24.65	8.65	9.15	7.05	7.50	8.75	6.00	10.15	8.15	7.50
4	12.10	9.70	22.75	8.20	8.85	6.90	7.58	8.60	5.88	9.65	7.95	7.95
5	10.45	9.75	20.25	8.00	8.35	6.55	7.08	8.30	5.78	9.60	7.65	8.10
6	10.70	8.90	15.20	9.70	7.95	6.35	6.78	7.95	5.70	10.10	7.50	8.55
7	10.20	8.15	13.20	7.70	7.50	6.30	6.53	7.85	5.60	9.45	7.50	8.10
8	8.70	7.85	12.70	8.40	7.45	6.25	6.35	7.65	5.50	9.00	7.65	7.70
9	9.15	7.78	14.90	[b]13.65	7.35	6.30	6.23	7.30	5.50	8.55	7.15	7.70
10	8.85	7.70	16.45	13.50	7.10	6.50	6.10	7.05	6.10	8.40	6.95	7.65
11	8.75	7.55	15.90	12.20	6.80	6.35	6.00	6.90	6.45	8.25	6.75	7.60
12	8.20	7.55	16.10	11.65	6.65	6.30	6.00	6.80	6.30	12.45	6.70	7.60
13	8.05	7.40	17.05	10.65	6.60	6.20	5.90	6.75	6.35	11.90	6.60	7.55
14	8.05	7.35	16.50	9.80	6.55	6.15	5.78	6.68	6.45	10.50	6.60	7.50
15	8.00	7.15	15.00	9.35	6.50	6.10	5.70	6.60	6.25	9.70	6.60	7.50
16	8.00	7.10	14.65	8.65	6.45	6.20	5.70	6.53	6.15	9.35	6.50	7.50
17	7.70	7.20	15.40	8.20	6.35	6.25	5.73	6.43	6.05	9.00	6.50	12.20
18	7.55	7.15	13.75	8.00	6.30	6.15	5.58	6.38	5.95	8.60	6.50	12.25
19	7.50	7.08	11.75	7.85	6.30	6.13	5.55	7.28	5.80	8.60	6.50	12.30
20	7.20	7.00	10.60	7.60	6.30	6.10	6.10	6.20	5.90	8.15	6.50	12.30
21	7.20	7.05	10.30	7.45	6.30	6.13	7.78	6.15	5.90	7.95	6.40	12.95
22	18.50	7.05	10.20	7.35	6.30	6.33	8.65	6.10	5.90	7.65	6.40	19.00
23	17.65	7.10	9.75	7.15	6.25	6.40	7.40	6.05	5.90	7.47	6.65	19.65
24	13.55	7.25	9.60	7.10	6.20	6.35	[c]11.00	6.10	5.90	7.37	6.30	17.20
25	13.15	7.30	9.45	6.95	6.20	6.20	[d]14.00	6.05	6.15	7.15	6.30	16.25
26	12.20	7.75	9.00	6.85	6.45	6.20	9.10	6.00	9.65	6.95	6.35	15.30
27	12.85	11.40	8.50	7.00	8.30	6.10	8.50	6.00	12.00	6.85	7.35	14.20
28	12.65	12.75	8.20	6.75	9.20	6.03	7.80	5.95	11.90	11.65	7.35	14.20
29	11.15	.....	10.20	6.65	8.40	6.13	7.45	8.25	13.45	11.25	7.10	13.80
30	9.50	.....	11.05	[e]11.75	8.30	7.00	7.45	6.95	10.35	9.45	6.95	12.30
31	9.25	.....	9.90	.....	7.90	.....	8.45	6.40	.....	8.95	.....	11.75

[a] Highest water 24.80 at p. m.
[b] Highest water 14.6 at p. m.
[c] Highest water 15.4 at 8 p. m.
[d] Highest water 16.6 at 9 p. m.
[e] Highest water 12.6 at p. m.

Mean daily gage height of Fishkill Creek at Glenham, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.95	4.57	4.05	3.97	3.90	17	3.73	3.85	4.15	4.55	3.95	6.18
2	.....	3.82	4.60	3.97	3.95	3.98	18	4.23	5.07	4.22	4.40	3.95	5.53
3	.....	3.77	4.47	4.10	3.95	4.05	19	4.00	4.70	4.12	4.32	3.95	5.15
4	.....	3.67	4.42	4.10	3.95	4.08	20	3.90	4.40	4.02	4.22	3.95	4.98
5	.....	3.65	4.30	4.00	3.90	4.10	21	3.77	4.45	4.02	4.20	3.93	4.78
6	.....	3.65	4.15	3.92	3.90	4.25	22	3.70	4.95	4.00	4.15	3.93	4.73
7	.....	4.70	4.17	3.90	3.92	4.28	23	3.65	4.62	3.92	4.12	3.90	4.73
8	3.90	5.55	4.10	3.87	3.95	4.18	24	3.65	4.70	3.90	4.10	3.90	4.55
9	3.90	4.77	4.07	3.85	3.90	4.05	25	3.65	6.40	3.87	4.05	4.35	4.60
10	3.80	4.35	4.02	3.85	3.87	4.73	26	3.62	6.55	3.85	4.00	4.33	4.55
11	3.78	4.12	4.05	3.85	3.87	5.33	27	3.60	5.65	3.80	4.00	4.13	4.85
12	3.83	4.07	4.37	3.80	3.92	4.83	28	3.45	5.20	3.87	4.00	4.03	4.15
13	3.80	4.02	4.32	3.80	4.32	4.60	29	3.57	4.85	3.95	4.00	4.00	5.75
14	3.73	3.90	4.15	4.30	4.17	4.68	30	4.35	4.70	4.20	4.00	3.98	8.28
15	3.70	3.90	4.10	4.85	4.05	6.78	31	4.15	4.57	.....	3.97	.....	7.50
16	3.65	3.82	4.25	4.82	4.00	7.45							

Mean daily gage height of Fishkill Creek, at Glenham, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.05	5.00	13.00	4.90	5.48	3.83	3.70	3.80	2.90	4.25	4.40	3.70
2	5.65	4.75	10.00	4.78	4.98	3.70	3.53	3.70	2.80	4.20	4.33	3.73
3	5.50	5.63	8.78	4.68	4.70	3.60	3.45	3.60	2.95	4.00	4.20	3.68
4	5.30	5.55	6.70	4.60	4.73	3.70	3.85	3.60	2.73	3.83	4.15	4.03
5	5.18	5.58	5.80	4.53	4.63	3.70	3.60	3.50	2.90	3.83	4.05	3.98
6	4.95	5.28	4.95	4.45	4.45	3.55	3.70	3.43	2.95	4.20	4.03	3.70
7	4.80	5.25	5.05	4.53	4.35	3.50	3.70	3.48	2.90	4.20	4.00	3.70
8	4.70	5.00	5.15	4.63	4.30	3.85	3.55	3.40	2.95	3.93	4.00	3.80
9	4.65	5.18	5.90	5.13	4.20	3.85	3.45	3.40	3.00	3.85	3.98	3.98
10	4.63	5.05	7.75	5.65	4.10	3.75	3.38	3.30	3.33	3.78	3.90	4.05
11	4.60	4.75	6.95	5.53	3.90	3.60	3.40	3.50	3.25	3.70	3.88	3.85
12	4.58	4.80	6.50	5.28	3.98	3.50	3.30	3.85	3.08	4.95	3.88	3.90
13	4.75	4.60	6.70	5.05	3.95	3.40	3.23	3.65	3.30	5.03	3.88	4.05
14	5.00	4.40	6.63	4.90	3.90	3.43	3.20	3.48	3.23	4.08	3.88	4.10
15	4.70	4.33	5.98	4.80	3.90	3.50	3.13	3.40	3.20	4.35	3.80	4.30
16	4.35	4.25	5.65	4.70	3.90	3.50	3.13	3.35	3.15	4.20	3.83	4.40
17	4.28	4.48	6.73	4.60	3.80	3.95	3.10	3.28	3.15	4.80	3.80	6.65
18	4.25	4.38	6.45	4.58	3.70	3.70	3.10	3.20	3.18	4.00	3.70	7.55
19	4.25	4.33	5.70	4.50	3.75	3.50	3.08	3.20	3.00	4.00	3.70	6.50
20	4.18	4.35	5.20	4.40	3.80	3.53	3.20	3.15	3.05	3.95	3.68	5.98
21	4.18	4.38	5.30	4.35	3.83	3.50	4.15	3.10	3.03	3.90	3.68	5.50
22	5.88	4.85	5.23	4.30	3.68	3.75	4.70	3.15	3.15	3.80	3.60	7.73
23	6.55	4.85	5.13	4.23	3.68	3.60	4.65	3.10	3.08	3.80	3.60	8.05
24	5.15	4.90	5.00	4.15	3.60	3.50	4.10	3.10	3.13	3.70	3.63	7.00
25	4.75	4.70	4.85	4.05	3.60	3.40	4.18	3.15	2.95	3.75	3.63	5.95
26	4.63	4.85	4.75	4.05	4.20	3.50	4.10	3.05	3.48	3.73	3.68	5.60
27	5.00	5.88	4.70	4.13	4.15	3.40	4.05	3.00	3.60	3.70	3.95	5.40
28	5.00	7.10	4.55	4.08	4.58	3.30	3.90	3.00	3.60	4.65	3.88	5.05
29	4.95	.....	4.85	4.00	4.23	3.35	3.80	2.95	4.80	5.43	3.80	4.93
30	5.05	.....	5.40	4.83	4.08	4.08	4.20	2.95	4.75	4.93	3.70	4.90
31	4.95	.....	5.05	.....	3.90	.....	3.95	2.90	.....	4.55	.....	4.77

Mean daily gage height of Tenmile River at Dover Plains, N. Y., for 1901.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1	.....	5.02	4.95	4.65	17	5.00	6.17	5.05	8.15
2	.....	4.80	4.90	4.67	18	5.30	5.87	5.90	7.20
3	.....	5.00	4.90	4.95	19	5.00	5.62	4.87	6.85
4	.....	5.00	4.85	5.50	20	4.85	5.50	4.87	6.35
5	.....	4.87	4.87	6.05	21	4.80	5.47	4.85	5.95
6	.....	4.85	4.87	5.40	22	4.80	5.40	4.79	5.75
7	.....	4.75	4.85	5.02	23	4.70	5.35	4.75	5.92
8	.....	4.65	4.80	4.80	24	4.60	5.27	4.75	5.20
9	.....	4.65	4.77	4.77	25	4.57	5.20	5.20	5.95
10	.....	4.65	4.75	6.35	26	4.50	5.00	5.10	6.40
11	.....	4.65	4.67	6.72	27	4.55	5.02	4.90	6.47
12	.....	4.65	4.97	6.35	28	4.37	5.05	4.95	6.50
13	.....	4.57	5.90	6.12	29	4.77	4.97	4.85	10.70
14	.....	6.27	5.50	6.47	30	5.50	4.95	4.72	12.30
15	.....	6.82	5.27	11.17	31	.....	4.92	.....	10.22
16	.....	6.42	5.10	9.50					

Mean daily gage height of Tenmile River at Dover Plains, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.70	5.40	14.15	6.60	6.95	4.55	4.45	5.10	3.90	5.78	5.75	4.45
2	7.00	6.10	14.10	6.45	6.95	4.50	4.25	4.88	3.83	5.85	5.50	4.48
3	6.95	6.95	[a]11.43	6.25	6.50	4.40	4.35	4.65	3.80	5.43	5.43	4.80
4	6.10	6.08	8.35	5.98	6.20	4.55	5.53	4.63	3.90	5.10	5.33	4.90
5	6.08	5.50	6.95	5.80	6.05	4.48	4.38	4.53	3.83	5.30	5.30	4.73
6	6.15	5.35	5.90	5.90	5.90	4.35	4.60	4.43	3.80	5.85	5.25	4.78
7	6.10	5.10	6.25	6.13	5.75	4.25	4.63	4.65	3.85	5.38	5.10	4.80
8	5.80	5.10	6.25	6.40	5.55	4.48	4.33	4.60	3.88	5.13	5.08	4.85
9	5.65	4.95	8.90	6.80	5.35	4.55	4.38	4.45	3.95	4.90	5.00	5.13
10	5.55	4.90	10.60	7.60	5.23	4.48	4.23	4.43	4.23	4.83	4.98	5.08
11	5.60	5.10	9.15	7.10	4.95	4.30	4.20	5.68	3.95	5.00	4.83	4.85
12	5.55	5.10	8.70	6.60	4.85	4.20	4.10	5.03	3.90	6.10	4.78	4.80
13	5.38	4.80	9.10	6.30	4.85	4.75	4.15	5.95	4.10	6.93	4.83	4.80
14	5.25	6.75	8.40	6.15	4.80	4.70	3.90	4.78	4.23	5.87	4.80	4.98
15	5.25	5.25	7.70	6.10	4.80	4.35	3.88	4.68	4.13	5.63	4.83	5.08
16	4.98	5.15	7.30	5.90	4.75	4.45	4.30	4.23	4.03	5.43	4.73	6.15
17	4.65	5.05	8.15	5.88	4.65	4.65	4.18	4.18	3.88	5.25	4.65	10.47
18	5.05	5.05	7.60	5.68	4.60	4.45	3.88	4.15	3.88	5.15	.....	9.13
19	5.10	5.00	6.55	5.58	4.65	4.28	4.03	4.15	4.03	5.27	4.60	8.28
20	5.05	4.85	6.13	5.45	4.68	4.15	4.65	4.18	4.28	5.20	4.53	7.70
21	5.05	4.75	6.10	5.35	4.58	4.40	6.98	4.25	4.33	4.90	4.55	7.74
22	11.95	4.68	6.15	5.23	4.50	4.60	7.15	4.23	4.13	4.80	4.58	11.50
23	8.10	4.40	6.20	5.13	4.40	4.38	6.35	4.10	4.15	4.75	4.55	10.65
24	6.35	4.50	6.25	5.03	4.30	4.33	5.75	4.08	4.08	4.73	4.53	8.58
25	5.80	4.65	6.05	4.95	4.30	4.15	5.68	4.08	4.05	4.65	4.58	7.95
26	5.70	5.83	5.90	4.95	5.05	4.10	5.50	3.98	4.08	4.55	4.70	7.48
27	7.80	8.45	5.85	5.30	5.30	4.05	5.30	3.93	4.65	4.60	4.93	7.05
28	7.45	9.73	7.43	5.25	5.50	4.05	5.40	3.85	6.50	7.05	4.78	.....
29	6.55	.....	7.60	5.30	5.18	4.10	5.25	3.83	7.75	7.10	4.65	.....
30	6.25	.....	7.30	7.00	4.80	4.70	5.65	3.80	5.98	6.37	4.33	.....
31	5.50	.....	6.90	.....	4.70	.....	5.25	3.85	.....	6.00	.....	.....

[a] Readings on new gage from this date, datum 0.33 above former gage.

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1900.

Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.
1	.....	3.2	4.9	17	.....	3.6	.....
2	.....	3.1	4.6	18	.....	3.5	.....
3	.....	3.1	4.3	19	.....	3.6	.....
4	.....	2.9	4.2	20	.....	3.7	.....
5	.....	3.0	5.6	21	.....	4.1	.....
6	.....	2.9	5.8	22	.....	4.0	.....
7	.....	2.8	5.4	23	2.9	3.9	4.8
8	.....	3.2	5.1	24	3.1	3.9	5.1
9	.....	3.5	4.9	25	3.2	3.8	4.3
10	.....	4.1	4.5	26	3.1	4.6	4.2
11	.....	3.9	4.2	27	3.1	5.5	4.1
12	.....	3.7	4.2	28	3.1	5.4	4.2
13	.....	3.6	4.2	29	3.1	5.1	4.0
14	.....	3.7	4.2	30	3.0	4.9	3.9
15	.....	3.7	.....	31	.....	.....	4.2
16	.....	3.7	.....				

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1901.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.40	3.20	3.30	5.30	6.20	6.20	3.60	3.50	4.30	4.30	4.00	4.00
2	4.00	3.30	3.50	5.30	6.20	6.00	3.50	3.70	4.40	4.20	4.20	4.10
3	(a)	3.30	3.60	5.30	6.40	5.70	3.80	3.50	4.70	4.50	4.00	4.20
4	(a)	3.30	3.60	6.10	6.30	5.50	3.90	3.40	4.60	4.60	3.80	4.10
5	(a)	3.10	4.10	6.60	6.00	5.50	3.70	3.30	4.60	4.40	3.70	4.00
6	4.50	3.00	3.90	6.50	5.60	5.20	4.00	3.30	4.40	4.20	4.10	4.00
7	4.50	3.40	3.90	7.30	5.50	5.20	4.00	3.90	4.40	4.00	3.80	3.90
8	4.40	3.50	3.60	8.30	5.30	5.50	3.80	4.80	4.40	3.90	3.80	3.80
9	4.20	3.40	3.50	8.00	5.20	5.50	3.80	4.40	4.00	4.00	3.80	3.90
10	4.40	3.70	7.50	7.80	5.20	5.40	3.80	4.10	3.90	4.00	3.70	5.00
11	4.10	3.50	8.20	7.20	5.70	5.20	3.90	4.00	4.00	3.80	3.50	5.50
12	4.70	3.30	7.50	6.70	6.30	4.90	4.00	3.90	4.20	3.80	3.60	5.90
13	4.00	3.40	6.00	6.50	6.10	4.80	4.00	3.70	4.00	3.80	4.80	5.70
14	3.50	3.70	5.50	6.10	6.00	4.60	3.90	3.70	4.00	5.20	4.90	5.80
15	3.70	3.60	5.60	5.90	5.60	5.20	3.60	3.60	4.00	6.70	4.70	8.20
16	3.80	3.40	5.60	5.90	5.50	4.70	3.50	3.70	4.10	6.00	4.60	8.20
17	4.40	3.40	4.60	5.50	5.30	4.50	3.70	3.60	4.10	5.80	4.50	7.[illegible]
18	4.00	3.40	4.60	5.30	5.30	4.20	3.60	3.70	4.70	5.30	4.40	7.50
19	3.50	3.20	4.80	5.20	5.80	4.30	3.60	4.00	4.50	5.10	4.20	6.80
20	3.40	3.30	4.80	5.20	6.20	4.20	3.60	3.80	4.40	4.90	4.30	6.10
21	3.80	3.40	10.00	7.30	6.20	4.10	3.60	4.10	4.20	4.80	4.20	5.60
22	3.60	3.50	8.70	9.30	5.80	4.00	3.50	4.70	4.20	4.60	4.20	5.10
23	3.70	3.40	7.40	8.40	5.80	4.30	3.40	4.80	4.00	4.50	4.10	4.90
24	3.50	3.20	7.10	8.50	5.60	4.70	3.60	4.80	3.80	4.40	4.20	5.20
25	3.60	3.30	6.60	8.80	6.80	4.60	3.60	6.80	3.90	4.30	4.60	5.20
26	3.70	3.00	6.60	7.85	6.70	4.30	3.50	6.70	3.80	4.30	4.80	5.00
27	3.80	3.40	7.20	7.20	6.80	4.20	3.50	5.70	3.80	4.20	4.50	5.30
28	3.70	3.30	6.90	6.90	6.80	4.00	3.50	5.20	3.80	4.00	4.00	5.10
29	3.50	.....	6.60	7.00	6.90	4.00	3.50	4.80	3.90	4.00	4.00	6.30
30	3.50	.....	6.20	6.40	6.80	3.80	3.40	4.60	4.40	4.30	4.20	9.40
31	3.40	.....	5.80	.....	6.60	.....	3.70	4.40	.....	4.10	.....	7.60

a Frozen.

Mean daily gage height of Housatonic River at Gaylordsville, Conn., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.10	4.90	14.30	6.80	6.80	4.70	4.80	4.80	3.80	5.50	5.50	4.10
2	6.50	4.90	10.80	6.60	6.30	4.40	4.60	4.65	3.55	5.50	5.30	4.15
3	5.90	5.40	9.90	6.80	6.10	4.40	4.40	4.65	3.50	5.25	5.00	4.40
4	5.30	4.90	10.20	5.80	5.90	4.60	4.70	4.45	3.60	5.15	4.95	4.60
5	5.20	4.80	7.80	5.80	5.60	4.90	4.50	4.30	3.65	5.00	4.85	4.60
6	5.30	4.60	6.80	5.50	5.50	4.80	4.50	4.40	3.55	5.15	4.75	4.30
7	5.30	4.50	6.50	5.50	5.50	4.60	4.80	4.60	3.65	5.00	4.65	4.35
8	5.20	4.40	6.80	5.70	5.30	4.60	5.00	4.55	3.50	4.85	4.60	4.30
9	5.30	8.50	6.80	6.10	5.20	4.40	4.70	4.55	3.55	4.70	4.50	3.45
10	5.10	6.80	7.50	6.80	4.90	4.60	4.50	4.45	4.00	4.55	4.35	3.55
11	5.00	7.00	2.20	6.90	5.00	4.50	4.40	4.50	4.00	4.40	4.30	3.70
12	4.90	8.00	7.70	6.80	4.90	4.50	4.30	5.15	3.90	5.30	4.45	3.75
13	4.70	8.80	7.80	6.80	4.90	4.40	4.20	5.00	3.85	5.30	4.40	4.00
14	4.30	8.30	8.00	6.70	4.80	4.70	4.00	4.70	4.10	5.10	4.50	4.05
15	4.50	8.00	7.90	6.20	4.70	4.60	3.90	4.50	4.00	5.00	4.50	4.25
16	4.50	7.10	7.70	5.90	4.60	4.30	4.10	4.35	3.60	4.80	4.40	4.90
17	4.30	6.80	7.90	5.80	4.60	4.50	4.20	4.20	3.70	4.75	4.35	7.90
18	4.20	7.00	7.60	5.60	4.50	4.40	3.90	4.00	3.75	4.60	4.25	7.35
19	4.40	7.50	7.30	5.60	4.40	4.40	3.80	3.80	3.80	4.55	4.30	6.70
20	4.20	7.30	7.00	5.50	4.30	4.40	4.65	4.05	3.85	4.25	4.25	6.35
21	4.50	7.20	6.60	5.20	4.60	4.30	6.00	3.95	4.05	4.30	4.30	6.65
22	8.50	7.20	6.60	5.20	4.40	4.70	6.60	4.05	3.75	4.45	4.20	8.60
23	6.80	6.80	6.10	5.10	4.30	4.50	6.00	4.10	3.60	4.40	4.20	8.40
24	6.30	6.50	5.90	5.10	4.10	4.30	5.70	4.10	3.70	4.45	4.05	7.55
25	5.80	6.80	6.00	5.00	4.20	4.30	5.50	3.95	3.65	4.45	4.15	7.30
26	5.60	7.00	6.00	4.90	4.50	4.30	5.30	3.95	3.85	4.40	4.25	6.90
27	5.90	10.60	5.90	5.00	4.60	4.20	4.95	3.95	4.20	4.30	4.60	6.65
28	5.70	9.00	5.90	5.10	5.30	4.20	4.85	3.95	4.60	5.85	4.50	6.00
29	5.30	.....	6.70	5.10	5.20	4.10	5.55	3.90	6.30	6.55	4.40	5.75
30	4.90	.....	6.70	6.20	5.00	4.30	5.45	3.90	6.00	6.00	4.25	5.90
31	4.90	.....	6.70	.....	4.70	.....	5.40	3.70	.....	5.80	.....	5.60

Current-meter discharge measurements of Catskill Creek at South Cairo, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Oct. 10	2.58	23.3	Hollister and Schlecht.
Oct. 4	2.70	25.6	W. W. Schlecht.
Nov. 8	2.70	27.6	Do.
Aug. 19	2.70	39.6	Hollister and Place.
Sept. 23	2.74	35.6	W. W. Schlecht.
Nov. 9	2.75	42.3	Do.
July 4	2.75	60.9	Horton and Hollister.
Aug. 1	2.80	47.9	A. E. Place.
Oct. 22	2.82	54.2	W. W. Schlecht.
Sept. 7	2.92	68.8	A. E. Place.
Aug. 9	3.00	81.5	Do.
July 25	3.00	81.9	Do.
Sept. 2	3.00	87	Do.
Aug. 27	3.12	121.4	Do.
July 17	3.50	260.3	Pressey and Place.
July 20	3.60	307.5	A. E. Place.
June 13	2.69	40.6	W. W. Schlecht.
June 24	2.70	43.5	Do.
Aug. 27	2.74	39.4	H. K. Barrows.
Sept. 5	2.79	50	Do.
June 3	2.82	49.5	W. W. Schlecht.
May 23	2.83	51.1	Do.
Sept. 22	3.32	121	P. M. Churchill.
July 9	3.365	113.5	H. K. Barrows.
May 10	3.47	133	W. W. Schlecht.
Aug. 13	3.49	135	H. K. Barrows.
Nov. 7	3.80	235	F. H. Tillinghast.
Dec. 3	3.90	275	Do.
Oct. 10	3.92	242	P. M. Churchill.
Apr. 22	4.06	320.2	W. W. Schlecht.
Aug. 2	5.36	1,005	H. K. Barrows.
July 23	6.11	1,602	Do.
Apr. 11	6.86	2,312	W. W. Schlecht.
Mar. 13	8.66	5,483	Horton and Schlecht.

A measurement made February 27, 1902, with the stream obstructed by ice, showed the discharge 363 second-feet, gage height 4.72. The stream was frozen from bank to bank to a depth of 6 to 8 inches.

Current-meter discharge measurements of Esopus Creek at Kingston, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Aug. 5	3.60	39.9	A. E. Place.
July 22	3.80	64.2	Do.
July 18	4.10	144.9	Do.
July 5	4.32	148	Horton and Hollister.
July 19	4.40	172.7	A. E. Place.
Nov. 18	4.45	126.5	W. W. Schlecht.
Sept. 26	4.55	167.8	Do.
Do	4.55	150.4	Do.
Aug. 19	4.60	180.2	Hollister and Place.
Oct. 10	4.62	165.8	W. W. Schlecht.
Do	4.62	188.1	Geo. B. Hollister.
Oct. 8	4.70	178.2	W. W. Schlecht.
Nov. 1	4.74	184.3	Do.
Nov. 14	4.75	195.4	Do.
Sept. 21	4.78	200.3	Do.
Aug. 10	4.85	259.2	A. E. Place.
Nov. 26	5.06	244.7	W. W. Schlecht.
Oct. 3	5.26	329.4	Do.
Sept. 6	5.46	352.2	A. E. Place.
Aug. 29	5.50	364.3	Do.
Oct. 21	5.56	380.8	W. W. Schlecht.
Aug. 8	5.65	396.1	A. E. Place.
Sept. 4	6.11	554.3	Do.
Aug. 27	6.26	728.6	Do.
Oct. 16	6.64	785.2	W. W. Schlecht.
Dec. 19	8.35	1,472	Do.
Dec. 11	11.46	1,720.8	Do.
Dec. 30	12.15	3,989	Do.
1902.			
June 16	4.48	135.8	W. W. Schlecht.
Sept. 4	4.49	133	H. K. Barrows.
Aug. 21	4.94	191	Do.
June 26	5.02	225	W. W. Schlecht.
June 5	5.03	234.5	Do.
July 16	5.13	268.8	H. K. Barrows.
Nov. 22	5.45	272	F. H. Tillinghast.
July 9	5.81	450.4	Barrows and Schlecht.
May 14	5.83	422	W. W. Schlecht.
Sept. 23	5.87	449	P. M. Churchill.

Current-meter discharge measurements of Esopus Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1902.	*Feet.*	*Second-feet.*	
Nov. 11	6	416	F. H. Tillinghast.
Aug. 12	6.28	550	H. K. Barrows.
May 24	6.38	[a] 274	W. W. Schlecht.
June 5	6.41	[a] 272	Do.
Nov. 5	6.56	594	F. H. Tillinghast.
Apr. 23	6.94	828.3	W. W. Schlecht.
May 14	7.14	[a] 508	Do.
July 30	7.65	1,155	H. K. Barrows.
July 24	8.11	1,348	Do.
Oct. 4	9.32	1,890	P. M. Churchill.
Mar. 12	9.90	2,843	Horton and Schlecht.
Apr. 30	10.28	2,813	W. W. Schlecht.
Apr. 10	13.37	5,021	Do.
Mar. 1	20.38	[b] 12,620	Do.

[a] Measured at Glasgow Bridge, Glen Eyrie.
[b] Large quantities of floating ice in the stream. Surface velocities used.

The following measurements were also made during the period of ice obstruction by W. W. Schlecht:

February 20: Gage height, 5.38; discharge, 245 second-feet; river partly frozen over. February 15: Gage height, 5.60; discharge, 557 second-feet; river mostly frozen over. February 7: Gage height, 6.83; discharge, 530 second-feet; river partly frozen. September 29, 1.30 p. m., the stream attained a flood stage, giving a reading of 25.25 on the gage.

Current-meter discharge measurements of Rondout Creek at Rosendale, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
July 18	6.30	118.2	A. E. Place.
Aug. 6	6.40	99.4	Do.
Nov. 7	6.42	138.2	W. W. Schlecht
Sept. 24	6.45	139.6	Do.
Oct. 11	6.47	163.2	Do.
Oct. 11	6.47	201.8	G. B. Hollister.
Nov. 16	6.55	183	W. W. Schlecht.
July 6	6.55	319	Horton and Hollister.
Aug. 15	6.55	225.4	A. E. Place.
Oct. 7	6.60	217.5	W. W. Schlecht.

Current-meter discharge measurements of Rondout Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Sept 7	6.90	426.7	A. E. Place.
Aug. 20	6.94	526.4	Hollister and Place.
Oct. 18	7.03	509.9	W. W. Schlecht.
Aug. 28	7.15	644.6	A. E. Place.
Aug. 8	7.50	745.4	Do.
Sept. 4	7.56	836.1	Do.
Dec. 21	7.60	772	W. W. Schlecht.[a]
Sept. 3	7.80	1,200	A. E. Place.
Dec. 12	8	1,490.8	W. W. Schlecht.
Nov. 26	7.21	675.4	Do.
Dec. 30	11.95	5,353	Do.[a]
1902.			
Sept. 25	6.31	167	B. M. Churchill.
July 15	6.33	141.9	H. K. Barrows.
July 18	6.33	137.2	Do.
Aug. 29	6.33	145	Do.
June 6	6.38	163	W. W. Schlecht.
June 20	6.42	166	Do.
Nov. 21	6.55	283.4	F. H. Tillinghast.
Dec. 2	6.70	367	Do.
Apr. 28	6.83	382	W. W. Schlecht.
May 12	6.855	421	Do.
Nov. 4	7.00	570	F. H. Tillinghast.
Aug. 7	7.39	838	H. K. Barrows.
July 29	7.40	888	Do.
Mar. 21	8.07	1,529	W. W. Schlecht.
Mar. 1	17.60	13,936	Do.
Apr. 11	11.78	5,666	Do.

[a] Stream somewhat obstructed by shore ice.

Additional measurements were made by W. W. Schlecht while the river was frozen over, as follows:

February 18, gage height, 7.70; discharge, 342 second-feet. The river was frozen over from bank to bank and slush had collected below the ice.

February 26, gage height, 8.13; discharge, 543 second-feet. Slush below the ice made an unsatisfactory record.

February 26, gage height, 8.43; discharge, 684 second-feet. Ice covered the river from bank to bank and slush had collected underneath.

The Delaware and Hudson Canal has been abandoned in New York State, with the exception of the portion from High Falls feeder on Rondout Creek to tide water, below Eddyville. The gaging station at Rosendale is situated opposite the canal level between locks 6 and 7. The water supply of this level is drawn entirely from Rondout Creek. In order to determine the amount of this diversion during the season of canal navigation, usually from April 1 to December 10, a record has been kept at lock No. 6, or Creek Locks, at the lower end of the Rosendale level. The record includes overflow at by-pass weir, water used for lockage, and flow through paddles in miter gates. There is also a small amount of leakage in the lock walls and gates which has not been determined. The flow in the canal at lock No. 6 added to the flow at the Rosendale station will give the total actual run-off from Rondout Creek above Rosendale. The following tables show the mean monthly and estimated daily diversion during the canal season of 1902. The estimated flow in the canal as recorded in 1901 is as follows:

	Second-feet.
October, 1901	30
November 21, 1901	19

Mean monthly diversion in second-feet to Delaware and Hudson Canal, lock No. 6, near Rosendale, in 1902.

	Second-feet.
March [a]	15.70
April	22.45
May	29.98
June	23.67
July	23.78
August	24.33
September	23.99
October	22.23

Current-meter measurements of Wallkill River at New Paltz, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Nov. 9	5.94	178	W. W. Schlecht.
July 23	5.20	306	A. E. Place.
Oct. 11	6.30	340	W. W. Schlecht.
Oct. 11	6.30	355	Geo. B. Hollister.
Oct. 24	6.33	333	W. W. Schlecht.
Oct. 9	6.48	398	Do.
Nov. 16	6.50	402	Do.
July 7	7.19	824	Horton and Hollister.
July 8	7.25	842	Do.

[a] March 23 to 31, inclusive.

Current-meter measurements of Wallkill River at New Paltz, N. Y.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
Oct. 1	7.36	896	W. W. Schlecht.
Nov. 27	7.52	1,022	Do.
Sept. 19	7.73	1,076	Horton, Place, and Schlecht.
Aug. 13	7.85	1,038	A. E. Place.
July 19	8.25	1,243	Do.
Sept. 5	8.90	1,676	Do.
Aug. 31	9.07	1,917	Do.
Aug. 20	10.00	2,729	Hollister and Place.
Aug. 28	10.60	2,982	A. E. Place.
Dec. 11	11.50	3,049	W. W. Schlecht.[a]
Dec. 19	13.70	3,277	Do.[a]
Aug. 7	14.85	7,365	A. E. Place.
1902.			
July 17	5.70	124.3	H. K. Barrows.
Aug. 28	5.86	169	Do.
Sept. 18	5.96	209.5	Barrows and Churchill.
June 19	6.18	295	W. W. Schlecht.
May 21	6.33	344	Do.
June 6	6.40	381	Do.
Nov. 18	6.62	550	F. H. Tillinghast
May 13	6.68	506	W. W. Schlecht.
Aug. 15	6.72	518	H. K. Barrows.
Dec. 2	6.80	626	F. H. Tillinghast.
Apr. 26	6.92	[b] 680	W. W. Schlecht.
Feb. 24	7.33	288	Do.
July 29	7.49	942	H. K. Barrows.
Apr. 21	7.57	[c] 1,028	W. W. Schlecht
Feb. 10	7.78	597	Do.
Nov. 4	7.95	1,165	F. H. Tillinghast.
Aug. 6	7.98	1,150	H. K. Barrows.
May 1	10.264	2,623	W. W. Schlecht.
Apr. 9	13.21	5,354	Do.
Mar. 11	15.93	7,140	Do.

[a] Stream obstructed by ice causing backwater.
[b] Measured through ice 1 foot 6 inches to 2 feet 6 inches in thickness.
[c] Measured through ice 1 foot to 2 feet in thickness.

Current meter measurements of Fishkill Creek, at Glenham, Dutchess County, N. Y.

Date.	Gage height	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
July 24	3.60	60	A. E. Place.
Oct. 12	3.80	97	Geo. B. Hollister.
Nov. 11	3.85	82	W. W. Schlecht.
Aug. 15	3.85	110	A. E. Place.
Sept. 27	3.86	90	W. W. Schlecht.
July 20	3.90	135	A. E. Place.
July 8	3.92	147	Horton and Hollister.
Nov. 20	3.95	114	W. W. Schlecht.
Oct. 5	3.98	126	Do.
Oct. 15	4.05	137	Do.
Sept. 6	4.15	193	A. E. Place.
Sept. 18	4.22	229	Do.
Dec. 24	4.52	315	W. W. Schlecht.
Aug. 21	4.56	342	A. E. Place.
Aug. 30	4.60	335	Do.
Dec. 13	4.62	375	W. W. Schlecht.
Oct. 15	5.10	579	Do.
Dec. 31	7.43	2,210	Do.[a]
1902.			
Aug. 26	3.04	48.5	H. K. Barrows.
July 14	3.18	64.4	Do.
Aug. 11	3.51	115	Do.
Oct. 11	3.71	155	P. M. Churchill.
June 2	3.785	132.3	W. W. Schlecht.
July 28	3.90	200	H. K. Barrows.
June 17	4.00	212.5	W. W. Schlecht.
Nov. 8	4.00	233	F. H. Tillinghast.
Apr. 25	4.03	[b]152.4	W. W. Schlecht.
May 6	4.46	349.5	Do.
Feb. 11	4.87	[c]202.5	Do.
Oct. 30	4.97	697.7	C. C. Covert.
Apr. 12	5.30	772.6	W. W. Schlecht.
Mar. 5	5.79	1,129	Do.

[a] Surface velocity used.
[b] Probably incorrect.
[c] Ice along banks at gaging station, frozen from bank to bank 90 yards below station 2 · · 9 inches thick.

Current-meter discharge measurements of Tenmile River at Tabor's bridge, below Dover Plains, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
Sept. 16	5.27	245.4	A. E. Place.
Sept. 28	4.36	70.3	W. W. Schlecht.
Nov. 11	4.75	121.5	Do.
Nov. 22	4.76	123.4	Do.
Nov. 22	4.76	120.9	Do.
Nov. 6	4.88	140.1	Do.
Oct. 26	5.01	187.6	Do.
Dec. 27	6.54	554	Do.
Oct. 15	7.19	692.8	Do.
Dec. 17	8.41	1,213.4	Do.
1902.			
Sept. 2	3.95	63	H. K. Barrows.
Aug. 19	4.28	100	Do.
June 10	4.45	[a] 158	W. W. Schlecht
Feb. 13	4.67	179	Do.
Aug. 4	4.69	184.8	H. K. Barrows.
Nov. 28	4.80	211.5	F. H. Tillinghast.
Nov. 14	4.87	211	Do.
May 15	4.88	230	W. W. Schlecht.
June 30	4.92	249	Do.
May 28	5.50	380	Do.
Oct. 2	5.80	443	P. M. Churchill.
Apr. 15	6.13	526	W. W. Schlecht.
Apr. 7	6.18	558	Do.
May 2	6.46	640	Do.
July 21	7.18	821	H. K. Barrows.
Mar. 3	10.41	2,386	W. W. Schlecht.

[a] River nearly covered with ice from bank to bank and 1¼ to 2¼ inches thick.

Current-meter discharge measurements of Housatonic River at Gaylordsville, Conn.

Date.	Gage height.	Discharge.	Hydrographer.
1900.	*Feet.*	*Second-feet.*	
Oct. 20	3	303	E. G. Paul.
Oct. 24	3.10	370	Do.
Aug. 10	3.25	422	Do.
Aug. 9	3.30	450	Do.
1901.			
Aug. 3	3.50	549.5	A. E. Place.
Sept. 28	3.78	700.8	W. W. Schlecht.
Sept. 13	4	911.7	A. E. Place.
Oct. 29	4.05	951	W. W. Schlecht.
Nov. 23	4.11	965.4	Do.
Nov. 13	4.82	1,863.7	Do.
Dec. 28	5.16	2,250	Do.
1902.			
Sept. 8	3.45	543	H. K. Barrows.
Sept. 19	3.75	640	Barrows and Churchill.
Aug. 20	3.95	835	H. K. Barrows.
Aug. 5	4.28	983	Do.
July 11	4.30	1,159	Do.
Nov. 29	4.40	1,281	F. H. Tillinghast.
June 23	4.46	1,177	W. W. Schlecht.
Nov. 15	4.50	1,356	F. H. Tillinghast.
Oct. 3	5.35	2,133	P. M. Churchill.
May 3	6.10	4,459	W. W. Schlecht.
July 22	6.68	5,119	H. K. Barrows.
Mar. 18	7.63	8,259	W. W. Schlecht.
Mar. 4	9.9	13,601	Do.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., October 1, 1902.

SIR: I have the honor to transmit herewith a manuscript by Waldemar Lindgren, geologist of this Survey, with the request that it be published in the series of Water-Supply and Irrigation Papers. This manuscript relates to the water supply of Molokai, one of the Hawaiian Islands. It was prepared from the results of an investigation made unofficially by Mr. Lindgren in 1900. The observations made at that time and the conclusions drawn from them have such general interest, as showing the possibilities and limitations of one of the group of islands, that it is desirable to make them available to the public. Of especial interest are Mr. Lindgren's notes on the gradual decrease of the forested area, the probable effect of grazing, and the intimate relations of these to the available water supply.

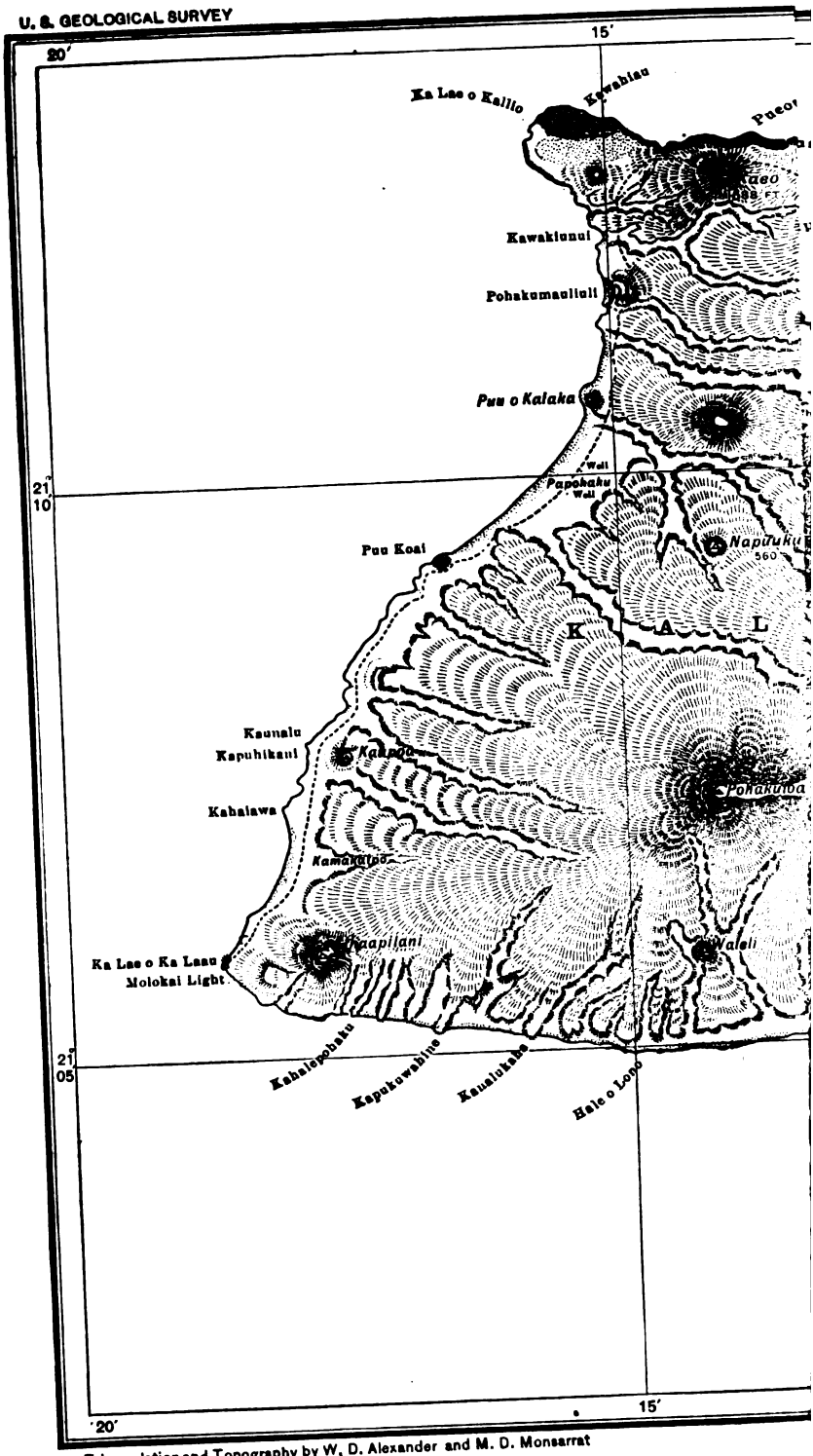
The problems of water conservation are here shown to be rather difficult and involved, but are similar in many respects to those of the arid West, the solution being found in combined systems of storage, water-power development, use of the power in pumping, the construction of wells, collecting tunnels, and the economical employment of various devices for lifting water. Opportunity is thus offered for the exercise of skill and mature judgment by the geologist, hydrographer, and civil and mechanical engineer.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director of United States Geological Survey.

U. S. GEOLOGICAL SURVEY



Triangulation and Topography by W. D. Alexander and M. D. Monsarrat
Hawaiian Government Survey

HE WATER RESOURCES OF MOLOKAI, HAWAIIAN ISLANDS.

By WALDEMAR LINDGREN.

INTRODUCTION.

Molokai is the fifth in size of the Hawaiian Islands, and is situated tween Oahu and Maui. Oahu is 23 miles distant, and from higher ints Diamond Head is in plain sight on clear days. From Maui is divided by a sound only 8 miles wide. Not much farther to the uth rises the dry, rocky coast of Lanai, a still smaller island, chiefly ed as a sheep range. Molokai is a narrow strip of land, extending miles from east to west and having an average width of a little less an 7 miles. The area is 261 square miles. The population in 1900 mbered 2,500. The island stands on the submarine plateau from hich the whole northern group rises, so that no extreme depths are und in the channel between Oahu and Molokai, nor between Molokai d Maui. Coral reefs fringe nearly the whole south coast of Molokai, it few occur on the north shore. This north shore is the windard side, receiving the full impact of the trade winds and a great nount of moisture. In strong contrast to this the south shore is tremely dry.

Molokai is outside of the ordinary course of travel. No description the island has ever been published, as far as I know, excepting mewhat stereotyped references to the leper settlement in books of avel. The more easily accessible portions are not attractive, and e northeast coast, which is characterized by wonderful scenery, is rdly ever visited by travelers.

TOPOGRAPHY.[a]

Three natural divisions may be recognized in the relief of the land: 1) The west end, or Kaluakoi; (2) the low gap separating Kaluaoi from the principal mountain range; and (3) the eastern range.

[a] The Hawaiians do not ordinarily designate directions by the four points of the compass. ey have instead two very expressive terms: *Mauka*, meaning upward, toward the higher rts of the island, and *Makai*, meaning the opposite, or toward the sea. It also seems that they not usually designate the water courses by special names, but instead apply to them the me of the subdivision of land through which they happen to flow. As will be seen from the ap, each subdivision has its own name.

The west end, or Kaluakoi, comprises about 55 square miles. This area consists of a broad, bare, and grassy ridge, beginning at the light-house at the southwestern extremity of the island and culminating, with an elevation of 1,382 feet, in the round-topped hill of Mauna Loa. Rocky and abrupt ravines lead southward from this backbone to the sea, while long gulches with gentler grade, and separated by broad ridges, reach the north shore. Here a steep cliff has been formed by the action of the waves (Pl. II, *A*). A sharp slope, or pali, a few hundred feet high, runs northward from Mauna Loa, dividing the west end from the low gap.

A low gap separates Kaluakoi from the principal mountain range of the island. The lowest point of this divide is 450 feet above sea level. Gently rolling smooth surfaces characterize this broad gap or saddle; on the south it is cut by shallow gulches and slopes gradually to the sea, while on the north shore the surf has sculptured a low sea cliff gradually merging into the great precipice or pali which from here on follows the northern coast. This gap contains the best and most extensive sugar-cane lands on the island, the total area being about 14,000 acres of deep red, extremely fertile soil. This area is sharply separated from the west end by Mauna Loa Creek on the south side of the island and by the above-mentioned low pali on the north. Eastward the rolling country gradually rises to the plateau of the main mountains of the island.

The eastern range comprises the largest part of the island. This may be briefly described as a segment of a circle, the chord of which extends east and west and has a length of about 25 miles. The line dividing the north-south drainage is, roughly speaking, parallel to the curve of the southern coast. The mountains culminate almost in the center of the island in the peak of Kamakou, which attains an elevation of nearly 5,000 feet. The south slope is gradual, and is furrowed by a great number of straight and narrow, though often deep, ravines (Pl. II, *B*, and Pl. III, *A*). The north slope is abrupt, in places precipitous, and is marked by five most extraordinary recesses or alcoves, cut in the face of the scarp. This great precipice and these alcoves are the most remarkable feature of the island's topography. North of the great gap of the island the great pali has a height of only a few hundred feet, which increases to 900 feet north of Molokai Home ranch and reaches 1,500 feet, where the trail to the leper settlement crosses it. From this point eastward the great precipice is much higher and from Waikolu to Wailau attains elevations of from 2,500 to 3,500 feet; then it gradually decreases again to Halawa, where it ends near the eastern point of the island, having there an elevation of 850 feet. The character of this pali may be seen from Pl. III, *B*, and IV, *A*. When of moderate height, i. e., up to 1,500 feet, it forms practically one continuous slope of from 50° to 70°, with practically no level land below. The surf beats directly against the foot of the escarpment.

A. SOUTH COAST OF MOLOKAI AT KOLO WINDMILL, WEST END OF ISLAND, LOOKING WEST.

Showing seacliff and successive basalt flows sloping down toward the coast.

B. MOUTH OF KAWELA GULCH, SOUTH COAST OF MOLOKAI.

Showing bowlder-filled creek bed and steep side slopes cut in basalt.

At the mouth of the Wailau Valley, and wherever it attains great height, there is usually a vertical or practically vertical cliff from a few hundred to a thousand feet high. Above this a slightly more gradual slope prevails, but for 2,000 feet above sea level the average declivity is often about 70°. Above this the slope flattens to something like 45°. The precipitous rock walls are channeled by a great number of parallel grooves cut by the rain water, and wherever the slopes are not vertical the dark colored rock is covered by a mantle of bright green vegetation. Only in one place is there is any important land mass projecting northward at the foot of the pali. That is the peninsula of the leper settlement, Kalaupapa, a rocky and dry peninsula 2 miles wide and 2 miles long, its highest point rising only a few hundred feet above the sea and marked by the crater of a small extinct volcano.

Next to the great pali itself the most remarkable features of the northern coast are the deep recesses or alcoves which erosion has carved into it, alcoves with exceedingly steep, sometimes perpendicular slopes, of wonderful beauty and grandeur, over the edges of which the waters of the upper drainage basins fall in numberless cascades, increasing to magnificent waterfalls during the rainy season.

West of Waikolu Valley the main divide of the island is close to the northern shore, but here it turns southeasterly and curving follows approximately the central line of the island. The three western alcoves, Waihanau, Waialeia, and Waikolu, have as yet not cut back very far and are therefore most characteristic of their type. All three have a shorter upper high level drainage consisting of small canyons in the high plateau, 200 to 400 feet deep, connected by cascades with the lower straight and deep canyons, 2 to 3 miles in length. The even verdure-clad side slopes descend at angles of from 40° to 60° to the water course in the bottom. At the head of the canyon the declivities become much more precipitous and form an amphitheater in strong contrast to the rolling or level summit plateau. At the head of the alcove and at various places from its sides the waterfalls descend like narrow white threads for 2,000 feet into the black depths of the chasm. Deep grooves and holes have been worn into the rock by the falls, so that in places they disappear altogether from view. More extensive and branching are the two principal streams of the island, Pelekunu and Wailau. They occupy watersheds of 4 or 5 square miles, but they, too, are surrounded by the same precipices, especially near the headwaters at the main divide. They are clearly of the same origin as the smaller alcoves, but a stronger erosive action has widened the valleys and extended their canyons. The grades of the streams are heavy throughout, and except at the north of the canyon there are practically no bottom lands. Pl. IV, *B*, shows the mouth of Wailau, with the broad, almost U-shaped form at the debouchure, and the furrowed slopes descending from the high plateau of the island.

The Halawa, another of the permanent streams of the island, flows in an easterly direction, heading in the swamps of the plateau east of Wailau, descending in a great waterfall to the lower alcove or canyon, and debouching near the extreme eastern end of the island.

From the headwaters of Waihanau to Kamakou, the highest peak on the islands, the summit region consists of gently sloping or hilly plateaus, generally swampy and cut by sharply incised ravines. The elevation of this plateau is only 2,000 feet south of the leper settlement but increases to 3,500 south of Waikolu and to over 4,000 between Waikolu and Pelekunu. Parts of the plateau project between the canyons, contrasting sharply against the precipices of alcoves and pali. From Kamakou for several miles eastward there is no central plateau, or only fragments of it. The drainage from north and south has cut in deeper and left only a sharp and jagged ridge. But between Wailau and Halawa there are again several square miles of the upper surface left.

The south slope of the island is very different from the northern. South of the divide the plateau gradually changes to a sharper slope, over which the water courses find their way in small cascades and falls. This decided slope is most accentuated on the Kawela, but is noticeable all along the south side of the island. The lower declivities, up to an elevation of 800 feet above the sea, are again gentle, having an inclination of from 5° to 8°, and a fringe of narrow flats follows the coast line. Instead of a few great canyons, some forty or fifty gulches and ravines form the drainage ways of the southern slope. All of these have the same characteristics, namely, a straight course, small drainage area, sharp grades, especially in their middle portion, and very abruptly incised sides, rarely, however, cut more than 400 or 500 feet below the slope of the surface. These conditions are the natural result of a comparatively recently established drainage system over the smooth sides of a volcanic cone. East from Kawela the straight, steep gulches are even more numerous than in the western part. Pl. III, *A*, shows the great Kamalo Gulch back of the plantation of the same name. It illustrates well the V-shaped form of the canyons as well as the partially preserved surface of the old lava cone. On the whole, the streams draining north are permanent, while those draining south carry water only during the rainy season, and then intermittently.

GEOLOGY.

Like the other islands of the Hawaiian group, Molokai is almost entirely of igneous origin. It is a volcanic cone built up in the middle of the ocean by a great number of superimposed basaltic flows. The island is, in fact, like Maui, formed by two volcanoes, and these two cones are separated by a low gap on which secular disintegration has reduced the basalt to a deep red soil.

A. KAMALO GULCH, SOUTH COAST OF MOLOKAI.

Showing parts of surface of volcanic cone, deeply dissected by gulches, débris fans at mouth of gulches, and coral reef below shallow water near shore.

B NORTH COAST OF MOLOKAI, LOOKING WEST FROM THE LANDING AT WAILAU.

Showing fault scarp along northern coast, horizontal basalt flows near base of cliff, and peninsula of leper settlement in the distance.

The west end forms one, separate and complete, though comparatively low cone. Partly obliterated craters are still visible near the summit, between Mauna Loa, Kaana, and Amikopala. The cone is not very regular, and secondary centers of eruption were probably located near the southwest and northwest corners of the island. The steep pali running north from Mauna Loa to the coast indicates a dislocation along which the east side has dropped a few hundred feet.

The main or eastern part of the island is not of so simple a structure. It represents one part, and probably the smaller part, of a large volcano, the northern part having dropped down along a great break or dislocation to a depth of from a few hundred to 3,000 or even 4,000 feet. Thus, the great northern pali, described in the previous pages, is really a break or a fault line, which split the volcano in two. The evidence of this is clear and convincing. The slopes of the lava flows are everywhere to the south, from 4° to 13°; even in the cliffs of the north coast the same inclination is observed. This, in conjunction with the form of the island, shows that a part of the volcano has been removed. Neither wave action nor erosion by running water could possibly have produced such an escarpment as that of the great pali, reaching 3,000 feet in height. The work of erosion on this cliff is shown plainly enough in the great alcoves cut by the water courses and described in previous pages. This erosion is still cutting southward and the divide is no doubt steadily migrating in that direction.

Dana, I believe, was the first to insist that the outlines of these islands have been to some degree determined by dislocations; and in his Characteristics of Volcanoes[a] is the only reference to Molokai which I have found in geological literature. It is as follows:

> Molokai was once, as its lava streams prove, a doublet of volcanoes like Maui, but it has been shaved down to a strip of land. The eastern part has an alcoved precipice facing the north, which rises to a height of 2,500 feet above the sea. Thus, such precipices are rather the rule in the Hawaiian group, and if seashore erosion is not the origin, fractures and subsidence must be.

Dana's view of the causes of the abrupt topography on the eastern coast of Oahu has been disputed by C. H. Hitchcock,[b] who believes that the action of erosion is sufficient to account for it. There is no doubt that deep canyons with very steep walls and almost perpendicular precipices near the heads of the water courses are most characteristic among the forms of erosion on the windward side of the island, and that, therefore, some caution must be exercised in discriminating precipices of erosion from those of fault scarps. However, in the case of Molokai, Dana's statement is undoubtedly true; the great pali is most certainly a fault scarp of magnificent size.

The low peninsula of Kalaupapa, the only land of importance at the foot of the cliff, seems to be a part of this sunken area, still above

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[a] 1890, p. 290. [b] Bull. Geol. Soc. Am., Vol. II, 1899, p. 23.

water. A crater and several lava streams still remain on this peninsula and are better preserved than most of those on the south side. The gently sloping summit plateau does not contain, as far as known, any remaining craters, but it is covered by extremely thick vegetation and few parts of it are accessible. Numerous smaller subcraters or parasitic cones remain, imperfectly preserved, on the long southern slope of the island. They generally have flat tops—the crater funnels being filled in—and intense red or yellow colors due to thermal action on the lavas. Such are Middle Hill, Puu, Luahine, Kakalahale, Maninibolo, and many others.

Similar in general to the other islands, the rocks of Molokai consist almost exclusively of dark basaltic, fine-grained lavas of more or less porous structure. The flows are thin, and range from a few feet up to 50 feet in thickness, but rarely exceed the latter limit. Laterally the flows are ordinarily not continuous over a great distance, hence exposures or wells only a few hundred feet apart may show very differing sections. Harder, more compact lavas alternate with exceedingly porous, loose breccias or agglomerates. The deepest parts of the gulches, the well sections, and the palis at Waikolu, Pelekunu, and Wailau all show the same structure, clearly indicating that the island has been built up by rapidly succeeding thin lava flows. The probability is very strong that this same structure and the same kinds of rocks continue down to a depth of several thousand feet. No petrographic study of the rocks has been undertaken, but a few thin sections make it evident that the rocks chiefly consist of normal feldspar basalt, somewhat glassy, and with olivine, occasionally also containing phenocrysts of soda-lime feldspars. Thus far the only kinds of rocks recognized by petrographers in the Hawaiian Islands are of the type of feldspar basalts, with occasional occurrences of nepheline-basalts or nepheline-melilite-basalts. In exploring the headwaters of Wailau, in the very heart of the dissected volcano of Molokai, however, an interesting occurrence of coarse-grained intrusive rock was found. Crossing the gap north of Mapulehu one descends over a precipice leading down to the valley of Wailau over a difficult and almost dangerous trail, which finally follows the bed of the east fork down to its junction with the larger west fork. Down to the junction only ordinary basaltic rocks are met with, but the west fork is full of heavy bowlders of a dark-green, coarse, granular rock, manifestly different from anything formerly described from the islands. The rock was not found in place, nor was the west fork followed up to its source, where these bowlders must come from. Indeed, in the thick tropical jungle which covers the whole watershed of Wailau, this is a very serious undertaking, but there must be a large mass of this rock in place, too large to have been carried up by the eruption of the lavas, and therefore it is most probably an intrusive body injected into the volcanic masses and there consolidated.

A. NORTH COAST OF MOLOKAI, LOOKING WEST FROM SUMMIT OF TRAIL TO LEPER SETTLEMENT.

Showing summit plateau and fault scarp, exposing a great number of basalt flows. Elevation 1,600 feet above sea level.

B. NORTH COAST OF MOLOKAI, MOUTH OF WAILAU VALLEY, LOOKING EAST.

Showing fault scarp 3,000 feet high and alcove type of eroded valleys.

Upon examination in thin section the rock presents a normal coarse granular structure, without glass, and consists of broad laminæ of a soda-lime feldspar not far from anorthite. Between these lie grains of a pale-violet, slightly pleochroic augite, with which are associated numerous grains of an iron ore. In addition, there are grains of olivine, slightly serpentinized, and in much smaller quantity than the augite. The rock is therefore a very coarse olivine-diabase.

Mr. Monroe, the superintendent of Molokai ranch, gave me a small specimen of a somewhat similar but slightly more decomposed rock which he had broken from a large bowlder in one of the principal streams on Kauai, the most northerly of the large Hawaiian islands. This proved to be very similar to the rock just described, being a coarse-grained diabase. A remarkable feature of the rock from Kauai is the deep purplish color of the augite. It is only slightly pleochroic.

These two coarse-grained rocks are the only occurrences of the kind thus far found in the Hawaiian Islands.

Unlike Oahu, Molokai has no extensive flats of sediment soil underlain by coral and tuffs. The sediments are chiefly confined to small strips and areas of less than 200 acres, and occur at intervals, especially near the mouths of the gulches along the south coast from Palaau to Pukoo. The soil is ordinarily, at no great depth, underlain by basaltic lava. Rarely is there a thin layer of coral rock between the soil and the lava rock.

The gap or the space between the two volcanoes which make up the island is of a rolling character and is covered by soil. A considerable part of this gap is covered by sediment soil, fine red soil, and well-rolled gravel, mixed. This sediment is doubtless chiefly carried down from the east side, and antedates the time when the volcano was split in two and the northern half engulfed in the sea.

As may be expected, the extremely steep gulches from Kawela eastward have brought down big fields of bowlders from the slopes above (Pl. II, *B*).

CORAL REEFS.

A coral reef from one-half to 1 mile wide fringes practically the whole southern coast of the island. The parts adjacent to the main gulches are gradually being filled up by mud. Thus, the island is gradually growing out in this direction. Seen from a high point, the reddish mud flats skirting the shore contrast strongly against the brilliant emerald green of the reef; and beyond this is the dark violet-blue color of the deep sea.

Small amounts of coral rock, indicating a former higher water level, are found all along the southern coast; usually these only reach 25 feet above water level, though in one place—near Puu Maninibolo—

this old coral reef extends up to 130 feet above the sea. The submergence was evidently of short duration.

The coral sand carried up by the waves forms a very narrow fringe all along the southern coast. A large dune wall of coral sand, about 12 feet high, skirts the western coast at Papohaku flats.

Though the coral reefs on the northern or windward side are not extensive, a very large area of dune sand occurs north of the gap and extends for several miles westward, having a width as great as 4,000 feet. The locality is particularly exposed to the full force of the trade winds, and the sand is carried up to the top of a 500-foot hill, where it accumulates in dunes which reach a thickness of 20 feet. Westward the sands finally reach the two creeks emptying near Papohaku, from which repositories the winter floods carry them down to the sea. Part of these dunes are consolidated to hard sandstones. In some of these are seen peculiar footprints which are similar to, and yet somewhat different from, the imprint of a human foot. There are also many obviously recent inscriptions, etc., and, as the Hawaiians are not altogether averse to a practical joke, the real character of these footprints may as yet be left an open question.

CLIMATE.

In regard to temperature, the island possesses the same equable climate as that enjoyed by the others of the same group; frost probably never occurs, even at the highest elevations. The trade winds are strong, especially during the winter months and on the northern coast. During long periods it is impossible to effect a landing at the settlements of Wailau and Pelekunu. Even along the south coast the winds are usually strong in the afternoon, and over the bare west end, or Kaluakoi, and over the gap the breezes sweep without hindrance. There is in general a wet season, extending from October until the end of May, and a dry season including the summer months. On the whole, the west end, the gap, and the south shore as far as Kamalo are included in the arid zone of the island, while the whole northeasterly part may be counted as one of abundant precipitation. All points over 2,500 feet in elevation receive an abundant rainfall. Most of this falls in the winter, but showers occur at intervals all through the summer. Accurate data regarding rainfall extending over any considerable period are not obtainable.

Data collected by Dr. Morritz at Mapulehu, on the southern coast and the eastern part of the island, from 1894 to July, 1899, show an average annual precipitation of 34 inches with but little variation and no apparent decrease. The maximum precipitation is usually in December, with as much as 6 inches, while the minimum monthly precipitation in the summer is 1 inch.

At Kaunakakai no records have been kept except for a month or

two in 1900, but it is apparent that the rainfall decreases rapidly west of Mapulehu. The probable annual rainfall at Kaunakakai does not exceed 10 inches, thus indicating a very dry climate. About 2 inches are said to have fallen in January, 1900. About 0.6 of an inch fell April 24, 1900, while since that time, up to July 1, 1900, there were only slight showers at great intervals; a little rain fell June 23, and again a little on June 27 and 28.

There are indications that the rainfall at Palaau, on the south side of the gap, is somewhat larger than at Kaunakakai, and this is, indeed, to be expected, for its position is more open to the northeasterly trade winds. On the north side of the gap precipitation is still further increased, as is indicated by the strong growth of grass, remaining green up to June 1.

At Molokai ranch, at an elevation of 850 feet and only a short distance from the gap, records have been kept by Messrs. Schleifer and Monroe since January, 1899, with the following results:

Rainfall at Molokai ranch.

Month.	1899.	1900.
	Inches.	*Inches.*
January	2	2.69
February	3.75	4.14
March	3	1.36
April	1.90	5.30
May	.50	.83
June	([a])	2
July	([a])	.....
August	([a])	.....
September	([a])	.....
October	1.23	.....
November	1.29	.....
December	1.71	.....
Total recorded	15.38	.....

[a] No record.

The figures for 1898–99 are incomplete. The season was one of great deficiency in rainfall, and this dry winter was followed by an exceptionally dry summer. The total for the rainy season 1899–1900 is 20.55 inches, indicating an annual rainfall at this place of about 22 inches.

At Meyer's ranch, at an elevation of 1,400 feet, about 2 miles northeast of Molokai ranch, records were kept for some time by Mr. R. W. Meyer, but I have only been able to obtain those of 1891. This year was, as the records show, an exceptionally dry one on Oahu and Maui. At Honolulu 23 inches fell that year against a normal rainfall of 38 inches. It is believed that the latter figure represents the normal rainfall at Meyer's ranch.

Precipitation in 1891 at Meyer's ranch.

	Inches.
January	7.65
February	3.28
March	.36
April	4.35
May	1.63
June	None.
July	None.
August	None.
September	None.
October	4.40
November	.20
December	1.26
Total	23.13

Above an elevation of 2,000 feet in this part of the island almost daily showers occurred from April 1 to May 28, 1900, and this is probably the normal condition during the winter months. Dry and warm weather prevailed from May 28 to June 8, when light showers fell. Again, on June 23, 26, and 27 there was a considerable amount of rainfall.

Regarding the quantity of rainfall in the mountains there is scant information. The annual precipitation probably reaches 100 inches at elevations of 3,000 and 4,000 feet and is not far from this amount over a considerable area on the north slope on the headwaters of Waikolu, Pelekunu, and Wailau.

It has been asserted that the rainfall on Molokai is decreasing. As far as the data go there is nothing to prove such an assertion. It is no doubt true that the island formerly supported a much denser population; this is indicated, for instance, by many old garden patches at streams which are now dry or carry water only intermittently. All this is, however, most probably directly chargeable to the destruction of the forests and the following irregularity or disappearance of the water supply.

SOILS.

The soils of Molokai are similar to those of the other islands of the Hawaiian group and are usually of great fertility. They may be divided into residual and sedimentary soils.

The residual soils result from the gradual decomposition of the basaltic lavas and are usually deep red, very rich in iron and in substances necessary for plant growth.

The sedimentary soils are partly of a deep-red color, partly dark brown, and not very different in character from the residual soils; they consist, in fact, of the same substance merely transported and redeposited. In a few places along the immediate coast line are small areas covered by coral sand, consisting largely of carbonate of lime, usually more or less mixed with detritus from the hills.

The west end of the island contains a very great amount of good, smooth land, with excellent soil. In fact, the larger part of Kaluakoi is of this character, excepting the southern slope of the long ridge extending from Mauna Loa to the light-house, the extreme northern and western portion, and the steep slope extending from Mauna Loa northward to the sea. The soil is residual in character. Unfortunately there is no feasible way of bringing water on this part of the island. It is at present used for sheep ranches and cattle range, being covered by a fine growth of nutritious grasses.

The finest body of agricultural land on the island is situated in the great gap, and has an area of about 14,000 acres. The principal problem of the water supply of the island is how to bring the water from that part which receives an abundant precipitation to this arid portion containing the rich soils. This area of gently rolling hills is covered by a deep-red soil unexcelled for purposes of sugar growing. To a great extent it is a sediment soil, as shown, for instance, along the western plantation fence near Mauna Loa Creek, where it follows the cane planted January, 1900. At this place a depth of from 20 to 30 feet of fine soil and disintegrated washed gravels is observed, resting on basaltic lava. This formation no doubt underlies a large portion of the cane lands. A part, however, of the eastern area on the rising hills is covered by residual soil derived from rock in place.

On the south shore there is a strip of low cane land near the coast at Palaau, but the main body of deep soil does not begin until an elevation of about 200 feet is reached. The total area of cane land at Palaau, below an elevation of 50 feet, is 374 acres.

Above an elevation of 800 feet, on the east side of the gap, there is, between the deeply incised canyons, a considerable amount of smooth land covered by grass and underlain by rich soil; but besides being cut up these areas are, by reason of their elevation, less suited for sugar cane, though well adapted for other crops. Thus, at an elevation of 1,400 feet, on the Meyer ranch, coffee is successfully cultivated in shady places without irrigation.

East of this point the island contains a relatively small amount of economically valuable soils. On the south coast the rocky slopes reach almost to the sea, leaving only in places narrow fringes of level land. On the north side the mountains, as indicated above, are very precipitous, and there is no arable land except small patches along the coast at the mouths of the rivers.

At high elevations the rock is, as a rule, much decomposed and retains water much better than do the stony slopes lower down. In the high swamps the mud is rarely over 2 feet deep, and solid, though decomposed rock comes frequently to the surface. The color of the soil in the swamps is grayish or white, showing that only ferrous oxide, produced by the reducing influences of organic acids, is present. After the swamps have dried up and the trees and ferns die, as has happened

over large areas in the high central parts of the island, this ferrous oxide under the influence of the air rapidly changes to ferric oxide. This forms a dark-red, hard-pan area on the surface which is very detrimental to young plants just rooting. This compact, dark-red soil is really an iron ore. A sample examined by Dr. E. T. Allen contained 43.88 per cent of metallic iron. This is one of the reasons why the reforesting of dried swampy areas is such a slow and difficult process.

For some distance east of Palaau there is a strip of sediment land along the coast containing 110 acres. Toward the sea this is joined by a salt marsh and toward the north by a rocky slope, which in part, however, can be planted. Near the cocoanut grove, 1¼ miles west of Kaunakakai, are 150 acres of excellent level soil underlain by 5 to 10 feet of coral which again rests on solid lava. At Kaunakakai about 100 acres of level rich soil are available. Between Kawela and Kaunakakai is a narrow strip of soil—mostly coral sand—which is covered by a thick growth of algarobas. At Kawela there is a considerable extent of sandy soil, practically all of which belongs to small native holdings. At Kamalo again several hundred acres of good soil are available, and from this place to the east point of the island a number of more or less extensive flats follow the coast, many of which are cultivated on a small scale. The lower part of the valleys of Halawa, Wailau, Pelekunu, and Waikolu contains a small amount of lands chiefly devoted to the growing of taro on a small scale.

VEGETATION.

In regard to vegetation, the southern side of the island may be separated in several zones. There is first the immediate coast fringe, distinguished by cocoa palms and algarobas; the barren zone; the belt of the grass lands; and finally the high forests.

The southern coast is fringed by a narrow, bright-green zone of thick and luxuriant algaroba trees (a variety of mesquit) which furnishes excellent firewood. The abundant bean pods of the tree are used as forage for cattle and horses. This strip is only a few hundred feet wide, but extends from Kawela Creek, almost without interruption, to a point a few miles west of Palaau. The western coast supports at Papohaku a few small and stunted groves of the same tree; the northern and eastern coast is too humid to permit the growth of this essentially arid-land tree. Occasionally, near springs at the seashore, the lahale trees appear, with clumps of bare trunks and palm-like tufts of leaves. This produces a fiber used for the manufacture of hats, etc. There is a large cocoanut grove one mile west of Kaunakakai. Few groves of this palm are planted east of this on the southern coast, though many places are excellently adapted for this purpose. Big thickets of the obnoxious weed Lantania grow on the coast near Kawela.

The barren zone of rough lava bowlders, with only a few bushes adapted to a dry climate, extends along the south coast, from the western point of the island to beyond Kamalo on the east. At Palaau it reaches an altitude of 200 feet; at Kaunakakai, 1,000 feet; and at Kawela, 2,000 feet. Toward Mapulehu the grasses reach sea level.

The pasture lands are covered by a thick carpet of manania (a variety of Bermuda grass) or delicate tufted Pele grass. Above a certain elevation (about 500 feet on the west end) these give way to annual grasses. Almost the whole of Kaluakoi, or the west end, is covered by pasture land; likewise the gap, excepting the arid strip near Palaau. Both of these areas are practically treeless. During the arid season the grass dries up. In the creeks and canyons east of the gap are found groups of kukui trees, with their smooth trunks and yellowish-green foliage bright with an almost silvery sheen. This is also called the candle tree, on account of producing a nut rich in oil. Many of these groups show signs of damage by cattle.

Isolated wili-wili trees are also noted, with their coral red bean and peculiar habit of shedding their leaves in the summer. Scattered cactus trees and hau bushes complete the meager flora of this zone. The finest and healthiest groves of kukui trees are found in the different branches of Meyers Creek above Meyer's ranch at elevations of about 1,000 feet. Parasitical ferns grow in profusion on the tree trunks. Papaia trees and coffee bushes do well wherever planted in these shaded canyons.

As the elevations increase, the grassy ground gradually becomes more swampy. Near Meyer's ranch the pastures are diversified by thick bushes of wild guavas, and ferns grow luxuriantly in the little gulches. Going upward from Meyer's ranch over swampy pastures and partly decayed forests, sometimes crossing little canyons thick with a growth of ferns, one is suddenly and unexpectedly stopped by the great precipice, the northern pali, here descending abruptly 1,500 feet to the sea, and showing along its steep escarpment the broken succession of the dark lava flows (Pl. IV, *A*). Far below, a silvery white fringe of breakers marks the shore. A rocky peninsula extends at the foot of the pali, and on its western side we notice a prosperous-looking town with regular streets and white cottages. Several churches and larger buildings are also seen, and many of the houses are surrounded by bright green gardens. This is the leper settlement of Molokai. A steep and somewhat dangerous trail leads down to the town. The inmates of the settlement are not allowed south of the pali, and at the little gate at the summit of the trail the unfortunates confined in the settlement often meet their friends.

In this vicinity the forests begin at an elevation of 2,500 feet, but the trees are in poor condition and on large areas are dying. It should be observed that all forests on this island grow on swampy ground. Open forests with trees growing on dry ground do not exist. The

lehua, a myrtaceous tree, in several varieties is most abundant. It has dark-green foliage and bright-red flowery tassels during the spring months. The height is usually up to 30 to 40 feet. More common on the north slope is the ohia or mountain apple, and the koa with its exceptionally hard wood. Around the moss-covered roots, frequently branching above ground, cluster the thick ului ferns (*Glauchenia*), and intermingled with the lehuas rise the pulu ferns (*Cibotium*) with their widespreading fronds up to 15 feet high. The whole is interwoven with a mass of tough eea vines (a kind of *Pandanus* or climbing screw pine) to a thicket which usually is almost impenetrable except along the beaten trails.

From Meyers Lake to east of Kaulahuki the forests, once said to be thick and healthy, are in a decaying condition. Kalamaula swamp is now partly dried. Around Kaulahuki extends a comparatively dry high plateau, and the peak itself is easily accessible. Going up over this plateau, rolling, grassy, and cut by sharply eroded little canyons, one comes suddenly to the great alcove canyon of Waikolu. The plateau is cut off sharply as with a knife; the eye sweeps down the black abyss of the precipices of the Upper Waikolu, and then down the V-shaped canyon to the sea. Narrow streams of water descend the faces like silvery threads on a black background. But at every place where there is a possibility of foothold a rank vegetation covers the rocks, and where the walls become a little less abrupt there is a solid area of dark-green foliage. At the brink of the canyon the mornings are often calm and clear, but before noon the sky and the sea mingle in one hazy bank and the strong trades drive dripping mists and intermittent showers over the swampy highlands.

A short distance east of Kaulahuki the horse trail ends and the whole country is covered by thick, healthy vegetation. Above Kawela the forests formerly descended far below Kolekole hill to an elevation of 3,000 feet. In its normal healthy condition the forest now extends along a width of only one-half mile on the southern slope. Traversing this thick swamp, clambering over slimy, moss-covered roots, and wading through deep mud, one suddenly emerges on the Pelekunu pali at an elevation of 4,500 feet. From this point can be seen the whole of Pelekunu drainage and part of Wailau, a green, impenetrable wilderness bordered by nearly perpendicular cliffs. Trails are said to cross the island into Waikolu and Pelekunu, but they are dangerous and difficult.

From Mapulehu an exceedingly bad though not particularly dangerous trail leads over into Wailau. Guided by Mr. Theodore Meyer I ascended the steep grassy slopes from Mapulehu to a more gently sloping path between narrow canyons, along which kukui, wild orange, and guava grow in profusion. We made camp at the edge of the forest 1,550 feet above Mapulehu. The next morning at sunrise a magnificent view was obtained of Haleakala, Maui's great

volcano, with its gigantic crater, seemingly only a few miles distant, but within a short time the usual clouds again hid the summit of the mountain. The track now enters the forest and ascends 1,200 feet in 1 mile, through lehua roots and mud, to Wailau Gap, which has the comparatively low elevation of 2,750 feet. The forest seems healthy, but Mr. Meyer states that it is much more open than formerly, probably due to grazing of cattle. In this part of the island there are, however, few cattle compared to the number kept in the western part. From the summit the extensive view over Wailau Valley reveals the same impenetrable sea of dark-green forest relieved by bright patches of wild bananas and kukui groves. Over slippery moss-covered rocks the trail descends 2,000 feet in 1 mile to the east fork, which may be followed for half a mile, by wading through water or jumping from rock to rock, down to the junction of the two forks, at an elevation of about 600 feet. Some distance before the east fork is reached we passed an abandoned kuliana, or native settlement, with a taro patch and a few exceedingly welcome orange trees.

The Wailau is a comparatively large stream, and its waters rush with torrential force in the narrow canyon. There is no further cultivated ground until near the mouth of the river, where considerable taro is grown and sent over by steamer to the leper settlement, partly whole, partly crushed to so-called "paiai" and packed in ti leaves. Pl. III, *B*, represents the native crew of the little steamer *Mokolii* engaged in loading paiai. We returned the same day to the camp above Mapulehu. The excursion makes an extremely arduous day's work.

CAUSES OF DECREASE OF FOREST AREA.

Many theories have been advanced as explanations of the decay of the forest. It has been attributed to cattle, deer, and goats, to decrease of rainfall, and to a disease of the trees.

It is evidently true that for many years the island has been overstocked, especially the good pastures at higher elevations, and it can easily be understood how the damage to the trees is effected. The cattle do not kill the trees directly, but they destroy the thick growth of ferns and grass which protects the roots and which is evidently essential to the life of the lehua tree. They also eat the young trees just coming up from seed. This has assuredly been the most prominent cause. But in many canyons where cattle scarcely can find their way, as well as in some parts of the swamps near the Pelekunu pali, the lehua trees are also dying, which indicates that the tree is besides suffering from some insect or fungus. The deer do less harm than the cattle, but it may nevertheless be well to keep their number within reasonable limits. In lower elevations goats abound, which should be removed as thoroughly as possible, for they completely destroy the already scant vegetation. Sheep have lately been confined to the western end (Kaluakoi), which seems most suited to them.

All in all, I believe that the cattle, in part aided by the disease referred to, are responsible for the decay of the forests and that it is not necessary to assume any material changes in climate. As mentioned, there is no such decay noticeable at Mapulehu, where very few cattle have been pastured. In consequence of the drying up of the swamps, the rainfall runs off rapidly and the streams become more intermittent and torrential in character, as indeed is very clearly marked in the case of Kawela. To remedy these conditions, I can only suggest the exclusion of cattle and other fern-destroying animals from the upper mountain region, which may cause the swamp ferns and lehuas to grow up again. The hard pan mentioned on page 20 is a serious obstacle to reforestation. Planting certain areas of land below the swamps by eucalyptus, acacia, or Monterey cypress would remedy matters to some extent.

FAUNA.

As well known, the native Hawaiian land fauna is exceedingly scant. A number of small birds inhabit the forests. Excepting a few centipedes, the objectionable insects are few in number. Many varieties of tree snails are found, often of beautiful color and delicate shell sculpture. More species of these are said to occur on Molokai than on adjacent islands.

The introduced animals are deer, goats, and cattle. The deer are of the spotted Japanese variety and have multiplied rapidly, so rapidly, indeed, that it has been found necessary to attempt to reduce their numbers, as they do considerable damage to the vegetation. Their principal range is on the high plateaus a few miles east of Meyer's ranch at the edge of the forest. The goats have likewise proved a nuisance, and it is difficult to keep in check their rapidly growing numbers. They chiefly range, practically wild, over the arid portion of the southern slope. It is surprising to observe their gymnastic performances when a band of them is scattered browsing on the ledges of canyon cliffs which a casual observer would pronounce perpendicular. The sheep kept on the Molokai ranch are chiefly confined to the western end of the island. Most of the cattle are now kept on Molokai ranch, including the west end, the gap, and a part of the southern slope as far as Kawela. Some of them run almost wild, but attempts are made to reduce that number, and also to keep them off the high forest areas. The island has been heavily overstocked with cattle, but the number is now reduced. East of Kawela there are comparatively few. For a limited number the western half of the island is a most excellent range.

CULTURE.

Tradition has it that in former days Molokai supported a far greater number of inhabitants than at present, and, further, that the forest covered much greater areas, even occupying part of the now treeless west end of the island. While, as explained above, it is doubtful

whether the rainfall has decreased, it is certain that with the destruction of much of the forest areas an equalizing element of much importance has been eliminated. From one end of the island to the other the coast abounds in stone fences and heiaus or square inclosures of stone connected with the worship of the gods. Evidences of old cultivation are apparent at a number of now arid places. Abandoned farms are found in the valley of Wailau; on the Pelekunu, a mile or two from the coast, old abandoned plantations of pineapples were noted. Such cultivation as now may be carried on by the natives is shiftless and imperfect. Taro is raised in the Lower Wailau and Pelekunu. Rice fields are cultivated by Chinese at intervals along the southern coast. A few small cocoanut groves are planted, but there is only one large grove, near Kaunakakai, said to have been planted by Kamehameha V. Small scattered kulianas contain a few oranges, mangoes, and papaias. On the whole, it is clear that with proper care and industry the island could support a far greater number of people than dwell on it at present. To some extent this undesirable state of affairs is doubtless due to the consolidation of properties into larger holdings for prospective sugar cultivation. But there is also a decided tendency of the natives to sell their small holdings and to move away to centers like Honolulu. The ranch of the Meyer Brothers, located about 5 miles north of Kaunakakai, shows what can be done even with comparatively small holdings when intelligent care is applied. Cattle are raised here, as well as some coffee and other products.

The population of the island aggregates about 2,400; but over 1,000 of this number are located in the leper settlement on the northern coast, established in 1865 and embracing about 8,000 acres. Of the remainder, several hundred are probably Japanese laborers, as the census was taken in 1900, when there were many of this class at Kaunakakai and Kamalo, so that there would remain only about 1,000 people scattered at Pelekunu, Wailau, Halawa, and the southern coast as far west as Kawela, for along the real arid part of the coast there are but few inhabitants. The total assessed value of Molokai was only $250,000 in 1897. In 1900 this figure had increased to about $686,000, due to the projects for sugar plantation advanced that year. In 1901, after the partial failure of these attempts, the assessed value decreased to $427,000. The Molokai Ranch Company, a corporation, controls the larger part of the lands on the western part of the island as far east as Kawela, and make a successful business of raising cattle and sheep on the extensive grass lands.

The American Sugar Company, closely connected with the Molokai Ranch Company, began operations in 1898 and 1899, controlling nearly the whole of the rich body of land in the gap, and the coast as far east as Kawela. It was proposed to bore for water at Kaunakakai, where 10,000,000 gallons per twenty-four hours (15.47 cubic feet

per second) were expected, and to raise this by means of pumps to an elevation of 400 feet to a ditch conveying it to the cane lands below the 350-foot level. It was further intended to obtain 20,000,000 gallons (30.94 cubic feet per second) 1 mile east of Kaunakakai and conduct it to a point 2½ miles away, where the water was to be lifted 500 feet to a short ditch conveying it to the lowest point of the gap, whence it could be distributed on both slopes. Eighty acres of seed cane were planted on the Kaunakakai flats and irrigated from a well giving 1,000,000 gallons in twenty-four hours (1.55 cubic feet per second). The failure of the Kaunakakai wells to produce the amount expected caused a change in the plans. It was decided to bore wells at the mouth of Kawela Gulch and raise the water about 70 feet to a cement-lined aqueduct, which should convey it to the high-lift pump mentioned above. Here, too, however, the quantity obtainable at one point seemed insufficient, and difficulty was experienced in avoiding contamination by salt water. Attempts were also made to find water by deep borings. In 1900 the company decided to abandon operations for the time being, and thus the problem how to obtain water for the rich sugar lands at the gap still remains unsolved.

The Kamalo Sugar Company controls the coast from Kamalo to Mapulehu. In this distance there are a number of smaller flats aggregating a considerable area. It was proposed to utilize these for sugar cane by wells bored along the coast and raised to a ditch about 70 feet above sea level. A small area of sugar cane for seed was planted at Kamalo and irrigated by means of a permanent small stream at the head of Kamalo Gulch. The water was taken out a short distance east of Kolekole Peak and temporarily conducted down in a ditch along the ridge. As Kamalo Gulch often contains running water, it was also proposed to utilize this source.

WATER SUPPLY.

GENERAL PRINCIPLES.

The fundamental law governing the water supply is that the only source of fresh water is the rainfall. A part of this rainfall is carried off by evaporation, another part by the streams, while a third and largest part sinks into the ground and gradually finds its way to the ground water, which permanently saturates the rocks below a certain level.

But on this small island, built up of extremely porous rocks, and surrounded by salt water, peculiar conditions result. In the absence of any impermeable stratum or basins filled by clayey material, such as, for instance, exist on Oahu, there is nothing to prevent the sea water from penetrating the rocks freely and assuming a level differing but little from the sea level. Below a certain level there is indeed no reason to expect anything but salt water.

On the other hand, the rain water also sinks freely through the porous rocks until it meets the sea water. Here, at the permanent water level, it is held by the counter pressure of the sea water, and in fact rests like a sheet on the same. Between the underlying salt water and the fresh water on top of it there is an intermediate zone of varying width in which the two mingle to form brackish water. The fresh water, always receiving additions from above, is slowly but steadily moving to the only outlet it can find—that is, to the springs located along the sea shore, just above or a little below sea level.

The surface of salt water is, apparently, near the coast on the south side of the island, about 160 feet below the surface of the ground. Inland this level sinks, and is also doubtless deeper on the north than on the south coast. The permanent surface of fresh water rises inland very slowly, so that a mile or more inland the water in wells may stand only a foot or two above sea level. Only at Kawela, a few hundred feet from the coast line, is the water level from 2 to 3 feet above mean sea level, and in this place a more abundant underground water supply is found than at any other point west of it. This generally low level of ground water is a distinctly unfavorable sign, pointing to small precipitation and water supply.

The one feature favorable to the percolation of the water to the southern coast line is that the lava beds all slope in this direction—that is, toward Palaau, Kaunakakai, and Kawela—thus to some extent guiding the water in this direction.

On the north coast the permanent water level is much higher, as indicated by the number of strong springs coming out at elevations of from 300 to 500 feet above sea level.

Above the surface of the ground water there may be some movement of water in cracks and fissures, but there is no permanent and abundant supply, certainly not on the south slope. Thus, tunneling on this slope is not apt to develop any considerable amount of water, though it may open some small fissures in which water circulates. As a matter of fact, very little water has been developed by the several tunnels driven near springs at higher elevations. If it were possible to drive a tunnel with very slight grade from sea level or from near the same, such an opening might develop a considerable amount of ground water; but this would be attended with many difficulties.

There is considerable irregularity in the amount of water available below the ground-water level. The porosity of the rock changes very rapidly; open, loose agglomerates are laterally adjoined by hard, much more impervious basalts. Further, the drainage conditions vary, the ground-water surface rising higher in one place than in another; thus in closely adjoining wells there may be great difference in the amount of water available from the same level.

The water from the flowing streams and from the springs emerging at high elevations contains practically no chloride of sodium, this being the only saline constitutent necessary to consider.

In the ground water along the coast the salinity is decidedly higher except where the ground water is mingled with water sinking from intermittent streams. The salinity increases with the distance from the center of maximum precipitation. Thus, at Palaau the water contains 90 grains, at Kaunakakai 50 grains, and at Kawela 25 grains per gallon.

In the following pages the available water resources will be described under the head of springs, streams, and wells.

SPRINGS.

The springs coming out on the southern slope of the island may be divided in three classes: First, those emerging at sea level. These are very numerous, and often, by reason of their vicinity to seashore, more salty than the normal ground water. Second, those appearing at elevations from 1,000 to 2,500 feet. Between the sea level and 1,000 feet no permanent springs appear, at least not west of Kamalo. Third, those of the summit region feeding the permanent streams. These will be mentioned under the heading of "Running streams."

On the north coast springs are more numerous and larger and emerge at any elevation. Strong springs appear in the Wailau and Pelekunu at from 300 to 600 feet above sea level.

SPRINGS ON SEASHORE.

No permanent springs are known on the whole north and west coast of Kaluakoi or the west end. A small spring has long been known to emerge on the south side of the ridge, near the summit, 2 miles east of the light-house, at at elevation of 180 feet, but it dried up in 1898 and has not been running since. At Waiakane, well below high tide, a strong spring of fair water appears.

The next important locality is Palaau. In the grassy marsh below the deep well big springs come out for a distance of 700 feet. Many old taro patches indicate that this water has been used. One of these springs flowed about 60,000 gallons a day (0.09 cubic foot per second), and the aggregate flow must be large. A sample yielded 103 grains of sodium chloride per gallon. On Naiwa, between Palaau and Halfway Camp, near a lone cocoanut tree, strong springs emerge from clefts in the basalt rock at the beach, 1 foot above high tide; the total visible flow may be as much as 170,000 gallons in twenty-four hours (0.26 cubic feet per second), and the salinity is 127 grains.

Half way between Palaau and Kaunakakai again a number of smaller springs appear, with a salinity of 86 grains per gallon. They emerge 1 or 2 feet above high-tide level.

The next locality is Cocoanut grove, 1 mile west of Kaunakakai, when very strong springs come out from the sand at the shore for a distance of 150 feet. The total flow is difficult to estimate, but it may

be over 200,000 gallons in 24 hours (0.31 cubic foot per second). The water contains 115 grains of sodium chloride per gallon.

Near Kaunakakai there appear to be no springs of importance, but 1 mile eastward, close to the road, a strong spring comes out from the basaltic rock at the foot of a bluff, 1 foot above sea level. Flow, approximately 6,000 gallons in 24 hours (0.01 cubic foot per second). The water contains 76 grains sodium chloride per gallon.

From this place to a point 1,000 feet east of Onini triangulation station no springs were seen at sea level, though wells find water at a depth of a few feet in most places, the sodium chloride in these amounting to about 115 grains. At the locality just mentioned a strong spring appears, and for a distance of several hundred feet much water comes out along the beach. The total flow must exceed 200,000 gallons in 24 hours (0.31 cubic foot per second). The sodium chloride amounts to 72 grains per gallon. A little water comes out east of this point as far as the end of wall around the fish pond. Again, small springs appear at the kulianas, just west of the mouth of Kawela Gulch. All of these springs east of Onini are under water at high tide.

The largest springs noted appear in the rice field east of Kawela Gulch, at the foot of a little bluff; they are 1.5 feet above sea level, and the aggregate volume of water measured by the discharge from the rice field is 450,000 gallons in 24 hours (0.70 cubic foot per second). The water contains 12 grains of sodium chloride per gallon. East of Kawela the coast was not examined in detail. Probably the coast springs continue all the way to Halawa and are fully as strong as at Kawela.

HIGH-LEVEL SPRINGS.

On the south slope, west of Kamalo, the springs issuing between 1,000 and 2,400 feet above sea level are exceedingly few in number.

The gulch heading north of Meyers at Puu Lua and emptying into the sea after flowing a few miles westward contains three springs. The principal one, at an elevation of 1,300 feet, yields at least 30,000 gallons in twenty-four hours (0.05 cubic feet per second), has no salt, and on May 21 flowed on the surface for a distance of at least one-half mile. Water comes out for a distance of about 1,000 feet; at the head two short tunnels have been run into the side hill without increasing the flow. At this place there is a watering trough, but the spring is said to be apt to run dry toward the end of the dry season. Another small spring inclosed by a stone wall is found in the next gulch just below Puu Lua. Lower down in a tributary to the same gulch, at an elevation of 1,000 feet, a little permanent water trickles out from the side and supplies a watering trough.

In the same vicinity, on Meyer's ranch, are two permanent springs. The first, 1,500 feet east of the trail to the leper settlement, at an elevation of 1,500 feet, yields continuously about 20,000 gallons in

twenty-four hours (0.03 cubic feet per second). The second, developed by a tunnel 300 feet long, drains toward Meyers Gulch and furnishes about 40,000 gallons (0.06 cubic feet per second), nearly all of which was developed by this tunnel.

A well-defined spring is that of Kapuna, at an elevation of 1,630 feet. This probably yields about 40,000 gallons (0.06 cubic feet per second), which is conveyed in a pipe line to the Molokai ranch. The water contains 3 grains of sodium chloride per gallon. It is permanent in all seasons according to reports. A short tunnel has been run in under the bottom of the gulch, but it failed to develop any additional amount of water.

In that branch of Luahine Gulch heading at Hunter's cabin, at the old wagon road leading up to the summit, a spring appears on the west side at an elevation of 2,400 feet, 30 feet above the bottom of the gulch. Its permanency is indicated by a bunch of wild bananas growing close by. The flow was measured on May 28, and was found to be about 77,000 gallons a day (0.12 cubic feet per second). The water is practically free from salt, but, according to reports, it dwindles down to a fraction of this amount during the driest part of the season. A tunnel 800 feet long has been run in under the hill in a north-northeast direction below the Kalamaula Swamp, but very little additional water was developed. The water comes out from the side and roof for short distance, while the rest of the tunnel is simply moist, giving no flowing water.

The only remaining spring at middle elevations is on Kawela, near its east boundary, in the gulch near Foster's mountain house, at an elevation of 2,500 feet. The water, which is pure and cold, amounted to 10,000 gallons a day (0.02 cubic feet per second), when visited, but the amount is less in very dry weather. From this point to Halawa no detailed examination has been made, but it is probable that springs are somewhat more frequent. At Mapulehu the swampy forests descend to 1,400 feet above the sea, and many springs are found at their lower edge.

RUNNING STREAMS.

STREAMS OF THE NORTH COAST.

On Kaluakoi there are no permanent streams; the gulches contain water only for a short time after heavy rains. Mauna Loa Gulch, emptying near Palaau, is the only one in whose upper course a little water runs during the larger part of the rainy season.

The gulches on the north coast west of the leper settlement are also dry except during heavy rains. The running streams to be considered are as follows: On the north coast, Waihanau, Waialeia, Waikolu, Pelekunu, and Wailau; at the east point, Halawa; on the south slope: Meyers, Kaunakakai, Kawela, Kamalo, Mapulehu, and Waialua gulches.

Waihanau.—The lower part of the Waihanau is a deep recess cut back from the pali, and over the edge of this recess, as indicated on the map, the stream flows in a series of falls. In the lower part of the valley the stream does not run during the summer. The upper part, which alone is considered here, has a drainage area of only about one square mile, but receives a great deal of rain water. Swamps line its borders, and much water comes in from springs on the sides of the abrupt canyon in which it flows, and which has a depth of from 300 to 500 feet. The grade is about 100 feet in 2,000. In the upper portion the stream is permanent though low in the dryest part of the season. I am informed by Mr. D. Center, the manager of the plantation at Kaunakakai, that when at its lowest stage the water will fill a 4-inch pipe lying nearly horizontal. This would correspond to about 80,000 gallons in twenty-four hours, (0.12 cubic feet per second). When visited on April 25, the flow was about 2,500,000 gallons a day (3.87 cubic feet per second), at an elevation of 2,046 feet. The weather was showery. On June 22, after three weeks of uninterrupted clear and warm weather, it flowed 1,500,000 gallons (2.32 cubic feet per second). On June 25, during the beginning of showery weather which continued for three days, the flow was 8,500,000 gallons (13.15 cubic feet per second). These results were obtained, as all of the following, at places where the stream ran with slight grade above and fell over an easily measurable natural weir, and should be accurate within 10 per cent. I conclude that the stream can be relied on for 3,250,000 gallons per twenty-four hours (5.03 cubic feet per second) from November 1 to June 1, for 1,000,000 gallons (1.55 cubic feet per second) from June 1 to August 1, and for at least 100,000 gallons (0.15 cubic foot per second) from August 1 to November 1.

Waialeia.—This stream has formed a deep recess from the pali, shorter but wider than that of the Waihanau. Over the nearly perpendicular wall of this recess it falls in cascades. The water in the lower part of the valley sinks during the dry season. Only the upper part above the precipice is here considered; it forms a small canyon extending back for a mile to Puu Kaeo. The watershed is only one-half of a square mile, but the supply is permanent, being fed by springs.

During the driest part of the season it fills, according to Mr. Center, a 2-inch pipe laid nearly horizontally. This would correspond to about 16,800 gallons in twenty-four hours. Measured May 24, during showery weather, at an elevation of 2,820 feet, a flow of 400,000 gallons (0.62 cubic feet per second) was obtained, which may be taken to correspond to average flow from November 1 to June 1.

Waikolu.—The Waikolu is a still larger and deeply cut canyon, surrounded near its head by almost perpendicular precipices, 2,000 feet in height. From the summit region belonging to its drainage three streams fall in grand cascades over these precipices. The

stream carries permanent water, which is used in the bottom of the valley for growing taro, the water rights of the lower part belonging to the leper settlement.

The area drained by the western branch of the Upper Waikolu is only one-half of a square mile, but practically all of it is swampy lands, insuring a good supply, permanent, though small, even through the dry months. The stream has cut a small canyon about 300 feet deep in this swampy plateau. The water was measured at an elevation of 3,645 feet on May 31, after three days of warm, clear weather following showery weather, which are practically normal conditions. The flow was 1,250,000 gallons (1.93 cubic feet per second), which may be accepted as the normal for the rainy season. The two other branches of the Waikolu head on the swampy, almost inaccessible plateau between Waikolu and Pelekunu.

Pelekunu.—Like the others on the north coast, this stream has cut a deep, alcove-like recess from the pali along the coast, continuously surrounded by precipices from 2,000 to 3,000 feet high. The highest part of this precipice is toward Kawela, while a narrow backbone, with an elevation of 2,500 feet, separates it from the headwaters of the Wailau. The watershed has an area of 7 square miles. In its lower course the grade of the stream is about 100 feet per 2,000, but above elevations of 1,000 feet it becomes very steep. The whole area is covered by extremely dense vegetation of ferns, lehuas, kukui, eea vines, and in many places wild bananas and mountain apples. Many large springs swell the lower course of the Pelekunu, coming out at elevations of from 300 to 600 feet. At an elevation of 350 feet the stream forks, the west branch again forking above this at an elevation of 425 feet.

On June 15 I visited the lower course of the river, ascending from the coast, there being no safe trail from the south side of the island to Pelekunu. The landing at Pelekunu is difficult, and on account of the heavy surf, practically impossible during the winter months. The weather for two weeks had been clear and warm, following a period of showers. The east branch of Pelekunu, measured at an elevation of 400 feet, contained 5,300,000 gallons (8.20 cubic feet per second). The middle or main branch, measured at an elevation of 475 feet, contained 11,700,000 gallons (18.10 cubic feet per second), while the west fork at the same elevation contained 4,500,000 (6.96 cubic feet per second), making a total of 21,800,000 gallons in twenty-four hours (33.73 cubic feet per second), from a watershed of 4 square miles. The question of minimum flow is a difficult one to answer without any measurements during the driest part of the season. A total of 5,000,000 gallons (7.74 cubic feet per second) at an elevation of 500 feet is certainly conservative; more probably the least flow would be 6,000,000 or 7,000,000 gallons (9.28 or 10.83 cubic feet per second). More observations during September or October are necessary to settle this point.

Wailau.—This, the largest stream of the island, is in general characteristics very similar to the Pelekunu. Its drainage area is slightly larger and is covered by the same dense vegetation. Precipices like those at Pelekunu, though scarcely as steep, surround the basin, which is narrower toward the sea than toward the head. A difficult foot trail connects Wailau with Pukoo and Mapulehu and crosses the mountain at a pass with the low elevation of 2,800 feet. From the summit gap the trail descends along the ridge between the two principal forks and reaches the east branch at an elevation of 690 feet; then it follows this for some distance and ascending again over the small point Puu o Wailau (elevation 680 feet), it reaches the junction of the forks at 470 feet. At the time of the visit, June 5, clear weather had prevailed for one week over the whole island, following showery weather in the end of May.

At an elevation of 500 feet the east fork contained 7,500,000 gallons (11.60 cubic feet per second), and at the same elevation the west fork contained 14,100,000 gallons (21.82 cubic feet per second), thus giving a total of 21,600,000 gallons in twenty-four hours (33.42 cubic feet per second) from an effective drainage area of 5 square miles. It will be noticed that the Wailau and the Pelekunu differ but little in their total flow; while the drainage area of the latter above 500 feet is slightly smaller, the elevation of its watershed and the precipitation is probably somewhat larger than that of Wailau.

Regarding the minimum flow the same remarks apply as have been made regarding the Pelekunu. Ten million gallons (15.47 cubic feet per second) is a liberal estimate of the least flow; more likely it is 8,000,000 gallons in twenty-four hours (12.38 cubic feet per second).

Several minor streams descend like silvery threads from the pali into the sea between Wailau and the eastern end of the island. Sometimes the strong trade winds dissipate these cascades into mist before they reach the foot of the escarpment.

Halawa.—Very near the eastern promontory the important watercourse of Halawa empties into the sea. Halawa differs from the other streams in flowing in an almost due east direction. Its watershed comprises about 8 square miles; it has its source in the swampy, impenetrable plateaus east of Wailau, and it descends from these in a beautiful waterfall plainly seen from the harbor. For a mile or two above its month it flows in a somewhat open, fertile valley. The minimum flow of Halawa is reported by Mr. O'Shaughnessy, former engineer to the American Sugar Company, to be about 5,000,000 gallons in twenty-four hours (7.74 cubic feet per second).

STREAMS OF THE SOUTH COAST.

Meyers Gulch.—This stream has a drainage area of 16 square miles, the largest on the south coast, but except near the summit it contains no permanent water, not even during the winter months. Its canyon

is sharply cut into the grassy plateau to a depth of from 200 to 300 feet, and contains in places thick groves of kukui trees. It empties a short distance east of Palaau. The grade in the lower course is moderate, but above an elevation of 1,500 feet it increases rapidly and the canyon contains many abrupt falls. The uppermost courses of the different branches have again a more gentle grade. At an elevation of 700 feet the creek branches. The east, or Luahine, fork heads with two prongs near the Hunter's cabin, on Kaunakakai land division, at an elevation of 3,000 feet; the main branch continues by Meyer's ranch, where it is joined by several smaller branches extending up toward Meyers Lake, and 1 mile above Meyers divides again into the Kahapakai and the Mokomoka branches, both of which head at elevations of about 2,600 feet in Kalamaula swamp.

During the winter of 1899–1900 the water in this gulch reached the coast four times—in December, April, May, and, lastly, June 27 and 28. The volume is considerable, sometimes 5,000,000 to 8,000,000 gallons in twenty-four hours (7.74 to 12.38 cubic feet per second), but the flow subsides rapidly. On June 27 about 5,000,000 gallons came down in twenty-four hours (7.74 cubic feet per second), while the next day there was but a slight stream trickling along the bed.

The permanent water appears chiefly in the Kahapakai Fork. Near its head, which is separated only by a narrow ridge from the canyon of the Waihanau, it is fed by strong and continuous springs coming in chiefly from the east side. Between 2,000 and 1,500 feet there is a sharp grade. Though the flow is small in summer the water runs permanently as far down as Wahii (elevation, 1,475 feet), where one branch of the water pipe supplying the ranch ends. Below this, on May 26, a little water was running, but only as far as the junction of the two forks.

On May 24, in light showery weather, Kahapakai was measured at an elevation of 1,975 feet, and flowed 281,000 gallons (0.43 cubic foot per second), diminishing at an elevation of 2,200 feet to 192,000 gallons (0.30 cubic foot per second). The same creek, at an elevation of 1,975 feet, contained on June 25 (light showers following three weeks of drought) 155,000 gallons (0.24 cubic foot per second). On May 26, after some pretty heavy showers, the water at Wahii measured only 151,200 gallons (0.23 cubic foot per second), showing that the maximum flow is at a considerably higher elevation.

The Mokamoka Fork does not contain as much water, nor is it permanent during the summer. On May 26 it was running only a little water one-fourth of a mile above the mouth of Kapuna Spring Gulch. Its average flow during the rainy season, at an elevation of 2,000 feet, may be estimated to be 150,000 gallons (0.23 cubic foot per second). The Luahine Fork of Meyers Gulch branches at an elevation of 2,000 feet, the two forks heading on each side of Kalualohe Hill. The west fork carries some water, about 100,000 gallons (0.15 cubic foot per

second), in the rainy season, and is said to run some throughout the summer. The east fork contains the spring mentioned above. The flow begins one-half mile above the tunnel and continues for at least the same distance below it. The maximum flow is perhaps 1,000 feet below the tunnel. On May 30 it gave 135,000 gallons (0.21 cubic foot per second).

Kaunakakai Gulch.—This gulch, debouching at Kaunakakai, has cut a long, narrow box canyon, and embraces a watershed of al out 8 square miles. It has a very straight course and is from 100 to 400 feet deep, the maximum depth being attained at the junction of the forks below Kaulahuki. From the west it receives some deeply eroded tributaries heading at Hunter's cabin, but these are usually dry, even through the rainy season. The main canyon has near the mouth a grade of about 100 feet in 1,500. In its middle course it is very steep, while on both sides of Kaulahuki lighter grades again prevail. The gulch contains running water in its middle and lower course only after heavy rain storms. Occasionally, very heavy freshets flood the plain at its mouth and bring heavy bowlders from the canyon. It is, in brief, a typical torrential stream. During the winter of 1899–1900 it was in flood in December; again in April, and finally in the last days of June, but each time the volume diminished rapidly, and after twenty-four or twenty-eight hours had dwindled to a very small amount. Below Kaulahuki, at an elevation of 2,500 feet, the main canyon forks—one branch, the Kamiloloa, heading between Kaulahuki and Kaeo, while the other, the Makakupaia, heads in the swamps around Hanalilolilo. Both of these branches carry permanent water. Kamiloloa during the period of examination carried water from its extreme head down to a point 3,500 feet above the junction. It is largely spring fed and its permanency is attested by a big bunch of wild bananas growing in the canyon at an elevation of 3,100 feet. On April 29 there was at least 200,000 (0.31 cubic foot per second) or 300,000 (0.46 cubic foot per second) gallons running. On May 31, after three warm, brighter days following showery weather, a flow of 276,000 gallons (0.43 cubic foot per second) was measured at an elevation of 3,100 feet. According to apparently reliable accounts it dwindles in extremely dry weather to 20,000 gallons (0.03 cubic foot per second). The main bulk of the water comes from the Makakupaia Fork, which is fed partly by springs but largely by the water stored in the swamps about Hanalilolilo. Below this point the Makakupaia forks again, both branches carrying water, though the eastern branch contains the larger part of it. The water, as in all of the streams heading in swampy ground, is of brownish color. The flow is continuous, even in the driest season, but, as in the case of Kamiloloa, it dwindles to a small amount. In the rainy season the water runs for a distance of several thousand feet below the junction, and even in the dry season it usually reaches the junction, according to state-

ments of Mr. Theodore Meyer. The stream was measured May 31, under normal conditions, three days of fair weather following showery weather, at an elevation of 2,510 feet. A flow of 450,000 gallons (0.70 cubic foot per second) was obtained.

Onini Gulch.—Though heading at 3,000 feet this gulch is ordinarily dry up to its head, only flowing after heavy rains.

Kawela Gulch.—The Kawela drains a territory of about 3½ square miles. It heads in the swamps near the highest peaks of the island and flows in a narrow box canyon from 100 to 500 feet deep. The grade near the mouth is 100 feet per 2,000, but in the middle course it increases to extremely sharp descents, broken by many perpendicular falls. In its upper course the grade is again less, perhaps averaging 100 feet in 1,000 feet.

Like Kaunakakai, this is a pronounced torrential stream, but it carries considerably more water. During the rainy season its flow very frequently reaches the sea continuously for several days. On an average the Kawela is in flood at least once a month between October and June. There is a great deal of water under its sandy flood plain, and the flow during freshets is depended upon to irrigate the kulianas (small holdings of native settlers) near its mouth. The flood does not stop suddenly, as in Meyers and Kaunakakai gulches, but continues for several days. The volume of water coming down is very large. On May 1, several days after showery weather, the Kawela, 500 feet above the forks, at an elevation of 160 feet, flowed at least 300,000 gallons (0.46 cubic foot per second), which at an elevation of 100 feet diminished to about 100,000 gallons (0.15 cubic feet per second). On May 28 Kawela had been flowing strong for several days; at an elevation of 100 feet there was a flow of 3,000,000 gallons (4.64 cubic feet per second). This gradually diminished, and on June 11 the creek was dry at the junction of the forks. On June 26 the creek was in flood again and continued so for several days, the amount on the day mentioned being at least 6,000,000 gallons (9.28 cubic feet per second).

The Kawela branches three-fourths of a mile above its mouth, and the two canyons have a parallel course only 1,000 to 2,000 feet apart to near their heads. Two miles above the mouth the west fork receives two tributaries which, however, are dry even during rainy season. The main west fork heads near Hanalilolilo and carries a little water, which rarely reaches the main junction. The ordinary winter flow is continuous for 2 miles below the head to a point below the high-water fall at an elevation of 3,000 feet, which may be observed from near Onini station. The flow was measured under normal, average winter conditions at an elevation of 3,350 feet, where its grade is comparatively flat, the result being 190,000 gallons in twenty-four hours (0.29 cubic foot per second). This little stream is probably nearly dry in the fall.

The main or east fork under average winter conditions flows as far down as an elevation of 1,500 or 2,000 feet. By far the greatest volume of its water is collected from the swamps near the head, and during rainy weather its volume reaches 5,000,000 to 7,000,000 gallons (7.74 to 10.83 cubic feet per second). On June 1, after three or four days of dry weather following showery weather, it was measured at an elevation of 3,160 feet, where its canyon has comparatively slight grade. The flow was 1,300,000 gallons in twenty-four hours (2.01 cubic feet per second). On June 19, after three weeks of hot and dry weather, it measured at the same place 350,000 gallons (0.54 cubic foot per second), at about which figure the flow, according to all accounts, remains constant during the summer, though in exceedingly dry weather it may dwindle as low as 50,000 gallons (0.08 cubic foot per second).

Kamalo Gulch.—This stream, together with the two adjoining gulches to the east, receives the drainage of the swamps of the highest mountain region, and in its general characteristics is very similar to the Kawela, though probably carrying a somewhat larger quantity of water. It usually flows at the mouth of the gulch once or twice a month. It is located on the property of the Kamalo Sugar Company, who use it to some extent for irrigation.

East of Kamalo no detailed observations were made. But, as stated above, the rainfall increases steadily in this direction, and grassy slopes descend far toward the sea. Between this place and Halawa the country is comparatively thickly settled. Little flats are common along the shore and little groups of cocoa palms and taro patches appear at frequent intervals. In this distance there are several streams similar to Kamalo and at least one permanent water course, the Waialua. The gulches are numerous and very closely spaced.

WELLS.

The fact that water can be obtained along the coast by shallow wells was recognized long ago, and irrigation on a small scale by means of windmills has been practiced in many places. Water for stock has been obtained in the same manner.

KALUAKOI.

On the western part of the property (Kaluakoi) precipitation is slight and the supply of ground water is accordingly limited and salty in character.

On the north coast, nearly due north of Mauna Loa, is located the Momomie well and windmill, used for watering stock. Here, as at all of the other stock wells, the surplus water is allowed to run back into the well. The depth is 35 feet, water standing at about sea level 30 feet below the surface. The salinity is very high—238 grains per gal-

lon. One mile eastward is an old landing place, where two small houses are still standing. A well 20 feet deep was dug here, but has been allowed to cave.

There are no wells along the coast west of this until Papohaku is reached, at the middle of the west coast. Several wells have been dug in the sandy plain which here follows the coast for about 1 mile. The well and windmill which supplies the stock is one-half mile southeast of Puu o Kaiaka; the depth is 40 feet, the water level, which is equal to the sea level, standing 35 feet below the surface. The water has a salinity of 403 grains to the gallon, thus closely approaching the limit for drinking purposes, even for stock. A quarter of a mile southwest is a smaller well, which probably stands at 200 grains and which is used by the stock men when stopping at Papohaku.

There is no further water until Kamakaipo, where, on the little plain adjoining the sea, a 30-foot well has been dug, the water standing 10 feet below surface. This well proved too salty for use. A smaller well close by, on the trail, is 10 feet deep and contains a little water which has about 150 grains of salt per gallon.

From the light-house to Palaau along the coast fairly good water is much more abundant and the four following wells and windmills are located here on the sandy shore. Alena well and windmill, 1 mile southeast of Waieli, depth 10 feet, salinity about like Kolo; Kolo well and windmill, 5 miles farther east, 7 feet deep, salinity 126 grains per gallon (Pl. II, *A*); Waiakane well and windmill, south of Mauna Loa, 4 feet deep, salinity 150 grains per gallon; Ioli well and windmill, near Palaau, 6 feet deep, salinity 109 grains per gallon, water stands 2 feet below surface.

PALAAU.

A number of wells have been bored near the coast at Palaau, all of them in the vicinity of the proposed site of the mill of the American Sugar Company.

Well No. 1.—This is a 12-inch well at stable 500 feet south of mill site, at an elevation of 22 feet. It is sunk in basaltic lava to a depth of 74 feet, the water standing at about sea level. The water contains 86 grains of salt per gallon. The well was pumped for four days continuously at the rate of 750,000 gallons (1.16 cubic feet per second) without change in water. It supplied the camp with water pumped up to a tank.

Well No. 2.—This is a 12-inch well below the railroad on west boundary of Hoolohua, at an elevation of 125 feet above sea level. It was sunk in basaltic lava to a depth of 140 feet, the water standing at sea level. The water contained 102 grains of salt per gallon when first struck.

Well No. 3.—This well is one-fourth mile east of stable and 100 feet northeast of deep well, at an elevation of 23 feet. It was sunk through

basaltic lava to sea level. In bottom 12-inch well sunk to 50 feet below sea level; very little water near surface. The water contained 86 grains of salt per gallon. This well was pumped for some time—just how long I was unable to find out; probably two weeks—at the rate of 750,000 gallons a day (1.16 cubic feet per second) without increasing the salinity.

Palaau deep well.—This well is located about one-fourth mile east of stable at Palaau, at an elevation of 22 feet above sea level. Total depth when work stopped, May, 1900, 250 feet. The surface formation was basaltic lava. At 180 feet some red tuff was met; at about 200 feet the rock was a coarse, open lava.

The first water, at sea level, contained 86 grains of salt per gallon; at 174 feet 90 grains were noted; at 180 feet from surface the well broke into salt water, which continued until the work was stopped.

Well in Meyers Gulch.—This is one of the oldest wells bored. It is located in Meyers Gulch, one-half mile above the railroad bridge and 1 mile east of Palaau, at an elevation of 50 feet above sea level. The total depth is 125 feet. Very little water, but of fair quality, was obtained at sea level; at 125 feet the well broke through into sea water.

Wells at mouth of Meyers Gulch.—There are shallow wells on the level plain at mouth of Meyers Gulch, at an elevation but little above sea level. Water stands 2 feet below surface. Water contained 90 grains of salt per gallon.

NAIWA.

The wells on this land are located near the mouth of a small dry gulch, 1½ miles west-northwest of the cocoanut grove. At 37 feet above sea level a shaft 10 by 10 feet is sunk 33 feet close by a 12-inch bore hole sunk to a depth of 70 feet. The first water, which stood at sea level, contained 74 grains of salt per gallon. Deeper, this increased to 90 grains. There is no record of pumping tests.

This locality was selected as repumping station for the high-lift pump intended to elevate the water to the 500-foot level.

KALAMAULA.

On this land, about 1¼ miles northwest of Kaunakakai, are situated the so-called cocoanut grove wells. They are located near the mouth of a little dry gulch, 2,000 feet from the sea, and in the northeast corner of a fine field of arable land which was plowed in 1900 and which it was intended should be planted to cane to be irrigated from these wells. Many good-sized springs come out on the seashore at the cocoanut grove; hence this was probably considered a good location for wells.

Cocoanut grove deep well.—This well is 27 feet above sea level.

Total depth is 343 feet. Diameter is 12 inches. Strata passed through are as follows:

	Feet.
Soil	10
Coral rock	5
Hard lava	25
Porous lava	75
Hard lava	35
Porous lava	193

Water was struck at sea level and contained 80 grains of salt per gallon. At 150 feet the water contained 91 grains, while at 160 feet the bore hole broke through into what was practically sea water and continued in it the whole remaining distance.

Cocoanut grove shallow well.—About 300 feet west of the deep well, at an elevation of 20 feet, is located another 12-inch well, 60 feet deep. One million gallons were pumped during twenty-four hours (1.55 cubic feet per second), the water containing 102 grains per gallon.

Cocoanut grove pits.—Beginning near the above-mentioned well a series of pits have been dug to below sea level. An excavation about 200 feet long and 15 feet deep has been made, and in the bottom of this 10 wells, 8 by 8 feet, have been dug to a depth of 10 feet, though some of them are not yet completed. While there seems to be a considerable quantity of water, no pumping tests have been made, the discouraging feature being that the water coming in ranged from 102 to 104 grains per gallon.

KAUNAKAKAI.

A number of wells have been bored at or near the mouth of Kaunakakai Gulch. Before the advent of the American Sugar Company there were at the mouth of the canyon several shallow wells on the property, on one or two of which windmills were erected. Water of a salinity of about 35 grains was obtained in sufficient quantities for the local needs of the small kulianas at slight depths, about equal to sea level. When undisturbed for some time the water from the upper part of the ground-water sheet contained only 12 grains of salt per gallon. A well at the Japanese hospital at the foot of the lava bluff, 1,000 feet west of the cane-field wells, was sunk to sea level, yielding water which contained 74 grains of salt per gallon.

The deeper wells bored by the American Sugar Company are as follows:

Cane-field wells.—Two wells have been sunk in the cane field from which during the year the 80 acres of cane at Kaunakakai have been irrigated. These wells are situated on the west side of the gulch at an elevation of 22 feet, have a depth of 60± and 75 feet, and are 40 feet apart. Both have a diameter of 12 inches. Water level was

reached after penetrating 22 feet of gravel and soil, the rest of the wells being bored in basaltic lava of varying hardness. Only the 60-foot well is being pumped. A supply of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) has been steadily obtained from it for over one year without increase in salinity, which is from 86 to 96 grains. A sample taken May 4 contained 84 grains. In the summer of 1899, however, the water was somewhat less salty than in 1900, for I find a record of July 10, 1899, showing that after two days of pumping from the first well (No. 1) the water contained 68 to 70 grains of salt per gallon. When the centrifugal pump, which now raises the water from the 60-foot well to an elevation of 40 feet, was connected with both wells the salinity increased to over 100 grains, showing that the deeper well had tapped some salty water.

The settlement well.—This is the most southerly of the long row of wells on the east side of the gulch. The elevation of the ground is 25 feet. The 12-inch well is 60 feet deep. The strata penetrated are largely soil, gravel, and soft lava, and there is, indeed, some doubt whether the bed rock was actually reached. A small pump elevates the water from this well to a tank from which the settlement is supplied. The well has yielded about 200,000 gallons a day (0.31 cubic foot per second) continuously. The water contains from 50 to 86 grains of salt per gallon. A sample on May 4 gave 83 gains; on June 11, 80 grains.

The three upper wells.—These are located on the west side of the gulch, 1,000 feet above the main pumping station and at elevations of 50, 60, and 63 feet. The depth of all of them is about 60 feet, water standing at sea level and containing 74 grains of salt per gallon. Except for a few feet of soil the wells are in lava of varying hardness. These wells have not been tested at all as to their capacity, as their high salinity seemed discouraging.

The deep well.—This well is the most northerly of the long row near the main pumping station. It has a diameter of 12 inches. The total depth at end of May, when discontinued, was 500 feet. The mouth has an elevation of 35 feet. Below 15 feet of gravel followed 25 feet of hard lava, below which porous, ashy, and caving lava was met down to 110 feet; from here to 150 feet followed hard lava, and then a porous stratum down to 250 feet. Below 250 feet hard and soft lava alternate, no special record being kept. The first water at sea level contained 50 grains of salt per gallon; at 160 feet the well broke into salt water, which continued until the work was stopped.

The 12 wells for main pumping station.—All of these are arranged in a row parallel to the bluff, and well No. 7, counted from south to north, has an elevation of 31 feet above mean sea level; from this elevation the other wells differ but little. All of the wells are 60 feet deep, except No. 13, which was known as the "donkey-engine well,"

and which is 75 feet. As in all of the wells bored, the absence of a detailed and reliable record is noticeable. Wells Nos. 7 to 13 reached bed rock at a distance of from 15 to 26 feet, indicating a decided slope southward. Below this only lava was met with, the hardness changing every 15 or 20 feet. In wells Nos. 2 to 6, inclusive, the bed rock was deeper, 26 feet below surface or more, and it is vaguely stated that every well showed a different record. In all wells the water was found at about sea level or, at most, 1 foot above it. The water when first struck contained from 20 to 40 grains of salt per gallon. Wells Nos. 1 to 12 were tested by pumping at the rate of 300,000 or 400,000 gallons in twenty-four hours (0.46 to 0.6184 cubic foot per second) from each for a few hours, the maximum salinity being 40 grains. Only No. 13 was tested somewhat more severely, being pumped four days at the rate of from 500,000 to 750,000 gallons per twenty-four hours (0.77 to 1.16 cubic feet per second). April 5, 1899, a sample from this well contained 11.5 grains of salt per gallon. Pumping at the mentioned rate from May 10 to 13 increased the salinity rapidly to 70 grains, and the last day it reached 83 grains.

After the erection of the 10,000,000-gallon (15.47 cubic feet per second) steam pump to draw from wells Nos. 2 to 13, inclusive, the pumping began in January, 1900. According to Mr. D. Center, at the beginning of the pumping the water contained 50 grains of salt per gallon. The pumps were started at 2,500,000 gallons (3.87 cubic feet per second), and after one week the salt had increased to 110 grains per gallon. After one month it had reached 200 grains and in March 400 grains, though when it went up to the latter figure both pumps were running at a total rate of 5,000,000 gallons (7.74 cubic feet per second). According to Mr. Boller, the engineer in charge, the quantities drawn were larger and for a considerable time varied between 4,000,000 and 5,000,000 gallons (6.19 and 7.74 cubic feet per second).

When it became clear that continued pumping would not bring in fresh water a series of tests were made to find out, if possible, from which wells the salt water came, but the result seemed to indicate that it was derived from all of them. Wells Nos. 2 to 6 seemed to contain better water than the others, the salt amounting to only about 150 grains per gallon. The quantity of water was, however, small, and these wells were easily pumped dry. In whatever way the other wells were arranged the water reached from 270 to 485 grains.

During heavy pumping from wells Nos. 7 to 13 their water level was lowered 1.5 or, at most, 2 feet.

Risdon wells.—These wells, so called because of the intention to erect a 20,000,000-gallon (30.94 cubic feet per second) Risdon pump on them, are located just 1 mile east-southeast of the Kaunakakai wells described above, at the eastern end of the cane fields. There

are twenty 12-inch wells 40 feet apart, located in three rows, which are also 40 feet apart with a northeast direction parallel to the dry creek near the mouth of which they are placed. They are bored at the foot of a low, rocky bluff, at the foot of which, 1,000 feet south of the wells, a strong spring appears. The most southerly well has a surface elevation of 28 feet, and a shaft is sunk from the surface to a depth of 20 feet, the well being bored 40 feet below the bottom of the shaft. Well and shaft penetrated 10 feet of soil, 2 feet of bowlders, 25 feet of hard lava, 23 feet of porous lava, below which again comes hard lava. All of the other wells have similar records. Salinity, 70 grains; water level, 1 foot above sea level. The most southerly well was pumped forty-eight hours at the rate of 750,000 gallons (1.16 cubic feet per second), after which the water contained 68 grains of salt per gallon and the water level was lowered 2 feet.

The other wells were tested by pumping with the deep-well pump at the rate of 300,000 gallons (0.46 cubic foot per second), but only for a short time. Maximum amount of salt, 74 grains per gallon.

KAWELA.

Between the Risdon wells and Onini station but little fresh water appears on the coast, but from the latter point to Kawela the indications favor a larger supply. On the sandy flood plain of the Kawela the kulianas find all the water needed in shallow wells, the level standing 6 inches above sea level. The water contains 3 grains of salt per gallon. During floods in the Kawela the ground water stands 1 or 2 feet higher than usual.

Up to June, 1900, 9 wells of an average depth of 55 feet had been bored at Kawela, all of them along the foot of the lava slope from 2,000 to 4,000 feet east of the creek. A number of kulianas or small holdings, usually owned by natives, are located on the sandy plain of Kawela and extend nearly up to the foot of the bluff.

Well No. 1.—This 14-inch well, started 12 feet above mean sea level, is 46 feet deep. The well passed through the following strata: Soil, 4 feet; hard lava, 10 feet; soft porous lava, 34 feet; hard lava at bottom. A good stream of water was met at 14 feet from surface. Water level stands 10 feet 9 inches below surface, giving the water level an elevation of 1 foot 3 inches above sea level. Water contains 15 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), the amount of salt rose to 25 grains. Subsequently, at the same time as the heavy pumping took place on well No. 3, this well was pumped for three weeks at the rate of 1,250,000 gallons in twenty-four hours (1.93 cubic feet per second), the amount of salt rising to only 37 grains.

Well No. 2.—This 14-inch well is 40 feet east of No. 1, at an eleva-

tion of 12 feet above mean sea level. It is 50 feet deep, and passes through the same rock as No. 1, except that bed rock is at the surface. Water was struck 10 feet below surface, and the level raised to 1 foot below surface (the only instance thus far noted of artesian pressure). On further boring, however, the water level sank to about 2 feet above sea level, showing that some very porous strata had been encountered. Water contained 18 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), highest amount of salt was 25 grains per gallon.

Well No. 3.—This 14-inch well is 40 feet east of No. 2, at a surface elevation of 11 feet. The well is 56 feet deep and passes through 2-foot soil, a few feet of porous lava, and then pretty solid lava until 9 feet above bottom, when a porous stratum was met. Water was struck 5 feet below surface, but at 46 feet depth it was easily pumped dry at rate of 1,000,000 gallons per 24 hours (1.55 cubic feet per second). The well was then sunk 10 feet farther, when a large flow of water was encountered. This single well was pumped for thirty days, March 1–30, 1900, at rate of 2,500,000 gallons (3.87 cubic feet per second). The water level was lowered 8 feet and the salinity rose as follows:

Amount of salt in well No. 3.

	Grains per gallon.
March 2	19
March 7	33
March 16	32
March 20	42
March 24	55
March 28	62
March 30	64

On May 16 the water level stood 8 feet 9 inches below surface of ground, or 2 feet 3 inches above sea level.

Well No. 4.—This 14-inch well is 1,080 feet east of No. 3, at an altitude 17 feet above sea level. It is 58 feet deep and passes through the following strata: Soil and gravel 4 to 5 feet, hard lava to 17 feet below surface, where a heavy stream of water was encountered and the water level raised to 13 feet below the surface; then followed a soft streak for 12 to 14 feet, and hard lava was again encountered in the bottom of the hole.

After short pumping with centrifugal pump it was decided to open the water-bearing stratum met 17 feet below the surface.

A pit was excavated about 12 by 24 feet, the longer side being parallel to the coast. The western half was sunk to 8½ feet below the surface, and a double-action two-cylinder 14 by 15 by 10 Worthington pump (strokes 86 per minute) was placed at this level. The eastern half of the pit was sunk deeper. On May 10 it had penetrated 15 feet

of hard but porous and open lava agglomerate. The water level stood 14 feet below the surface while pumping at the rate of 2,500,000 gallons (3.87 cubic feet per second). The water level in the deep-bore hole No. 4, situated in the middle of the western end line of the pit, was 1 foot lower. On May 10 the water from pump contained 37.5 to 40 grains of salt per gallon. Pumping began May 8 at 9 a. m. and continued with some intermissions to June 25, when the pumps were removed to well No. 6.

On May 16 the pit was down to 16 feet from surface, while the water stood 14 feet below, and work was becoming difficult. Pumping at the same rate was continued, the water containing 46 grains of salt per gallon. The water could not be handled with the Worthington pump, so a small centrifugal pump was added. On May 28 both were running with a total capacity of 3,500,000 gallons (5.42 cubic feet per second). Water coming into the big pit on northeast side 5 feet below sea level contained 29.5 grains of salt per gallon, while the discharge from the main pipe ran 40.4 grains, but contained up to 60 or 70 grains after some hours of continuous pumping.

In the first days of June a 2,000,000 gallon (3.40 cubic feet per second) centrifugal pump was substituted for the smaller one and total rate of pumping increased to 4,000,000 or 4,500,000 gallons (6.19 to 6.96 cubic feet per second). The water was discharged into a flume and was conveyed to the pond near the eastern boundary of Kawela. Up to the end of May the 20-inch suction pipe had been allowed to remain in the bore hole drawing up salty water all the time, but then this pipe was first shortened and finally placed in the bottom of the pit. The total depth of the pit from surface of upper (north) side is 18½ feet. Tunnels were now started from the northeast and southwest corners of the pit. On June 8, 2 p. m., pumping 4,000,000 gallons continuously, the water in the northeast tunnel ran 40 grains of salt per gallon, while the water in the flume contained 90 grains. On June 11, pumping continued as before, keeping water within 16 feet of bottom, the heavy stream of water from northeast tunnel ran 35 grains of salt per gallon. Another heavy flow, pouring from the well hole, contained 78 grains. The water in the main discharge flume contained 64 grains; later in the day 82 grains. A big stream of salty water also poured out 1½ feet above bottom of pit in southeast corner; a less amount of same on south side of northeast tunnel but only at its mouth, and still another smaller flow near southwest corner of pit. It had now become apparent that salt water came in from the bore hole and from the south side of the pit near the bottom. A futile attempt was made to check the flow from the bore hole by piling bags filled with earth around it. A week later the well hole was filled with cement, but only to a depth of 20 feet below the bottom of the pit, total depth below it being 40 feet. The pumping was

continued at same rate and the water contained the amount of salt indicated in the following table:

Amount of salt in water from No. 4 well.

[Grains per gallon.]

Date.	Northeast tunnel.	Southwest tunnel.	Flume.	Southeast flow.
June 12	39	27	120	200
13	48	38		
14—9 a. m	48	38	198	341
12 noon	51	52		394
15—2 p. m	57	33		
4 p. m				480
19 [a]	56	65	127	
20—12 noon [b]			125	
4 p. m	45	65	150	225
21 [c]				
22—9 a. m [c]	52	68	110	162
4 p. m	65	48	150	232
23—9 a. m	49	60	111	
4 p. m	52	37	142	232
24 [d]	57	32		
25 [e]				

[a] Pumping stopped for two days.
[b] Running day time only.
[c] June 21 about same as June 20.
[d] No pumping.
[e] Irregular pumping.

All tunnel samples were taken at face.

On this day the tunnel had advanced 32 feet from the pit. The rock, which had been porous and soft, was becoming hard at face, and much water was coming in from the roof. The southwest tunnel had advanced 23 feet in porous rock, but the same was becoming hard, a good stream of water coming in from the floor.

An analysis of above data shows that the two tunnels furnished from 2,250,000 to 2,500,000 gallons (3.48 to 3.87 cubic feet per second) of water, containing on the average 50 grains of salt per gallon, while the southeast flow and the bore hole furnished from 2,000,000 to 2,250,000 gallons (3.10 to 3.48 cubic feet per second), containing from 200 to 400 grains of salt per gallon. Practically all of the salt water comes from these two sources. The rapid increase in salinity from the southeast flow and the bore hole shows that there are leaks in the rocks at these points in almost direct connection with the sea water, while the other parts of the pit had no such connections. It might well have been possible to isolate these sources of contamination.

Well No. 5.—This 14-inch well is located 226 feet east of No. 4, and is 75 feet deep. It passed through the following strata: Soil 3 feet, hard lava to 29 feet from surface, soft red lava tuff to 47 feet from surface, hard lava to 70 feet from surface, soft again from 70 to 75 feet. The water stood 9½ feet below the surface, or 2½ feet above sea level. On May 16 I measured water level to 9 feet 1½ inches below surface. Salinity, 35 grains. Pumped with centrifugal pump at rate of 750,000 gallons (1.16 cubic feet per second) May 8 and 10, but not

continuously. On pumping the level immediately fell 2 feet 3 inches. Highest salinity, 35 grains.

Well No. 6.—This 14-inch well is located 255 feet west of well No. 4 and is 60 feet deep. It passed through the following strata: Soil and gravel with bowlders, 40 feet, remainder lava, in part soft. Water contains 25 grains of salt per gallon. Was pumped two days with well pump (capacity, 300,000 gallons, or 0.46 cubic foot per second). Water stands normally 15 feet 6 inches below surface. Pumped also intermittently from June 11 to June 16 at rate of from 500,000 to 850,000 gallons (0.77 to 1.32 cubic feet per second), the water level only being lowered 3 to 4 inches. On June 16 the water contained 31 grains of salt.

Well No. 7.—This 14-inch well is located 240 feet west of No. 6, and is 59 feet deep. It passed through soil and gravel 30 to 35 feet, below this lava of varying hardness. There were no pumping tests up to June 30 on account of lack of available pumps.

Well No. 8.—This 14-inch well is 240 feet west of No. 7 and has a total depth of 58 feet. There have been no pumping tests.

Well No. 9.—This 14-inch well is 195 feet west of No. 1, at an elevation of 20 feet. Down to some feet below water level hard lava prevails. The well was not finished by end of June. There are no special tests of water from the last three wells, but the amount of salt ranges from about 25 to 35 grains per gallon.

On the west side of Kawela Gulch a shaft was sunk at an elevation of 30 feet in a small side gully. Water containing only 3 grains of salt per gallon was found somewhat above sea level. The water came in too fast for bailing, but no pumps being available nothing further was done at this locality.

Other wells.—Since the middle of May, 1900, a series of six shafts (5 by 5 feet) have been sunk to sea level between the wells, but no pumping has been done on these. It was proposed to extend a tunnel from well No. 4 to well No. 1, a little below sea level; this tunnel was to grade toward No. 1, where a central pumping station was to be located, and was to collect the upper stratum of the ground water, to which that from the deeper strata down to 60 feet was to be added by pumping from the wells. As it was shown, however, that tunneling under existing circumstances was quite difficult at well No. 4, it was intended at the time of my departure from Molokai to substitute an open cut and trench for the tunnel.

THEORETICAL AMOUNT OF WATER AVAILABLE.

The rain falling on the island is disposed of in the three following ways: One relatively small part is evaporated from soil and from plants. A second and large part is absorbed by the soil and, continually moving, sinks down to the surface of permanent saturation, which slopes gently seaward; all of this water finds its way to the shore and must emerge from the rocks at or about sea level. A third

part runs off in the living streams. On the north coast and in the summit region this amount reaches at least one-half of total rainfall, for the ground here contains much water and only slowly absorbs more. Over the south slope the run-off is very small, for the living streams are here largely absorbed before reaching the sea. The run-off of the total south slope is probably only 30 per cent of the total rainfall. It is greater at Kawela than at Kaunakakai.

Absolute data can not be obtained on account of lack of information as to rainfall; but, taking all conditions known on this and adjacent islands, the following approximate calculation may be made:

Total area of south slope from Meyers Creek to east boundary of Kawela is 54 square miles; average rainfall over this area is 4 feet per year; total annual rainfall over this area, 6,048,000,000 cubic feet, or 45,358,000,000 gallons, or 126,000,000 gallons per twenty-four hours (194.95 cubic feet per second); evaporation, 26,000,000 to 36,000,000 gallons (40.23 to 55.70 cubic feet per second); run off, 20,000,000 to 30,000,000 gallons (30.94 to 46.42 cubic feet per second); ground water, 60,000,000 to 80,000,000 gallons (92.83 to 123.78 cubic feet per second). Of this amount it was proposed to secure nearly one-half, or 30,000,000 gallons (46.42 cubic feet per second), at one place near Kaunakakai, which clearly would be impossible.

The ground water available from one-half mile west to 1 mile east of Kaunakakai and from the coast to the summit, including the drainage of Kaunakakai and small gulches to the east, may be roughly calculated as follows:

Area, 36,000 by 12,000 feet; average rainfall over whole area, 4 feet; total amount of water, 1,728,000,000 cubic feet, or 13,000,000,000 gallons per year, or 36,000,000 gallons in twenty-four hours (55.70 cubic feet per second); evaporation, 8,000,000 to 12,000,000 gallons (12.38 to 18.57 cubic feet per second); run off, 5,000,000 to 10,000,000 gallons (7.74 to 15.47 cubic feet per second); available for ground-water circulation, 14,000,000 to 23,000,000 gallons in 24 hours (21.66 to 35.59 cubic feet per second), which amount must emerge along the coast. It is thus seen that a considerable amount of water is available, though it is probably distributed pretty evenly over the distance, and its long passage through the rocks has rendered it salty. The fact that for a whole year 1,000,000 gallons (1.55 cubic feet per second) has been pumped from the cane-field well goes to prove that there must be a fair amount available along the coast.

A considerable amount of ground water is available at Kawela Gulch. Assuming a drainage area of 24,000 by 12,000 feet for the Kawela property and an average rainfall of 5 feet, for the rainfall is decidedly more than over the Kaunakakai drainage area, we obtain 1,440,000,000 cubic feet, or 10,800,000,000 gallons a year, or 30,000,000 gallons a day (46.42 cubic feet per second). Assuming 6,000,000 to 10,000,000 gallons (9.28 to 15.47 cubic feet per second) evaporation, 4,000,000 (6.19 cubic feet per second) run off, 16,000,000 to

20,000,000 (24.76 to 30.94 cubic feet per second) remain for the ground water that may be considered available near Kawela Gulch. While the total supply is not much larger than at Kaunakakai it is more concentrated and the water is less saline, the normal flow averaging about 35 grains, the flood water on top sometimes going as low as 3 grains.

These calculations of the relative quantities at Kaunakakai and Kawela may not quite express the actual conditions, for from the geologic structure it seems very probable that a large part of the ground water from the headwaters of Kaunakakai Gulch finds its way down to Kawela, thus considerably increasing the amount available there.

The ground water probably available at Kamalo may be roughly estimated as follows:

Assuming a drainage area of 20,000 by 10,000 feet and an average precipitation of 5 feet, we obtain a total of 7,500,000,000 gallons a year or 21,000,000 gallons a day (32.49 cubic feet per second), of which the larger part, perhaps 12,000,000 or 15,000,000 (18.57 to 23.21 cubic feet per second), should be available at or near the mouth of the gulches. Several more favorable locations may be selected between Kamalo and Mapulehu which should aggregate 10,000,000 gallons (15.47 cubic feet per second).

Considering now the high region above with a view to ascertaining how much water may be available for an irrigation system collecting the run-off of the area from the head of Kawela to Waihanau, we may approximately calculate as follows:

Total area involved, 32,000 by 4,000 feet; average rainfall, approximately, 8 feet; total amount of water, 1,024 cubic feet or 7,680,000,000 gallons a year, equivalent to 21,300,000 gallons a day (32.96 cubic feet per second). The run-off, which is here at least 50 per cent of total precipitation, would be 10,500,000 gallons (16.25 cubic feet per second).

The drainage area of the upper Waihanau is 10,000 by 2,500 feet, over which a rainfall of 8 feet may be expected. Total water, 200,000,000 cubic feet, or 1,500,000 gallons per annum; it is proposed to collect the entire run-off of this; the amount estimated by stream measurements is 710,000,000, which is a little less than half of the total precipitation.

UTILIZATION OF THE WATER SUPPLY.

The principal problem on Molokai is how to obtain water for irrigation of the 14,000 acres of deep soil situated in the great gap. Another problem is how to obtain water for the irrigation of the smaller coast flats occurring at intervals from Palaau to Mapulehu.

According to the ordinary estimates of sugar planters, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) are needed to irrigate 100 acres of sugar cane. In the opinion of many this is too much, but at that rate 14,000 acres would necessitate 140,000,000

gallons per twenty-four hours (216.61 cubic feet per second). Assuming 1,000 acres of coast flats, 10,000,000 gallons (15.47 cubic feet per second) more would be needed. It is evident that such an amount of water is not available on the island. A certain amount of water can, however, be obtained and it is of interest and importance to attempt to estimate this quantity. Sooner or later the welfare of the island may demand that all possible resources be made available. First of all, the running water at high elevations must be considered. In a few places, as at Kamalo, this water is carried down in steep-grade ditches to irrigate fields at the coast. This plan is probably impracticable in the long run, for these ditches will soon be washed out and there is great loss of water by absorption. If this plan is to be considered, it would be necessary to conduct the water in iron pipes, but the quantity in each place is usually small, so that it would also be an expensive undertaking for the results achieved. Another plan would be to collect the water of the upper region as far east as Kamalo and to carry it by a series of ditches to storage reservoirs above the cane lands. This would be more feasible and such a plan is considered in the following pages. The supply would entail small expense for maintenance. If cemented ditches were used in places the plant would be put on a permanent basis, necessitating no renewal every ten or fifteen years, as is the case with flumes. There is a further source of supply in the ground water along the coast. This can be collected, carried by flumes or cemented ditches to a point near the cane lands, whence it would have to be raised 400 feet by means of a force pump. Few agricultural industries but sugar plantations could bear such a tax, but, as well known, there are many such high-power pumping plants in the islands, especially on Maui. The expense would be still further increased by the necessity of many well plants, for it is certain that no one place will supply a very great quantity of water. There is a possibility of using electric power, which may aid to solve the problem. At any rate, I think it certain that the coast flats could easily be irrigated from wells, which would not necessitate high pumping.

Another point to be considered is the salinity of the waters. The running streams are very pure, but all of the ground water is more or less contaminated by common salt or sodium chloride. There is less of this at Kawela and Kamalo and to the east, but west of Kawela the salinity increases and reaches 90 grains per gallon at Kaunakakai and Palaau. The danger point in using saline water for sugar plantations is stated to be about 100 grains per gallon. Above this the waters become undesirable and their application may spoil the lands, especially if they are low lying.

UTILIZATION OF THE RUNNING STREAMS.

The amount of water which yearly flows to the sea through Meyers, Kaunakakai, and Kawela gulches is not large, though the torrents are

violent while they last. To collect this amount at sea level would be difficult in many respects, and this plan is not to be recommended; nor will it be less difficult to collect the water from the streams while running at elevations of 500 to 1,000 feet. Flumes would be long and expensive, and the long seasons during which they must remain dry would necessarily soon destroy them.

The only place to economically collect the running water is near the summit region. Here the streams are more constant and less torrential; here, also, is the region of heaviest rainfall and largest relative drainage area. In their lower course most of the streams are in box canyons which can not collect a large amount of water.

It may be thought that flumes have been used too extensively in the scheme outlined below, and in some places where the soil is very light ditches may possibly be substituted, but the danger of losing water by leakage is great, though not so great as farther down the slope, and in installing the system tests and measurements should be constantly made to make sure that no avoidable losses take place. During the dry part of the season most of the streams will flow only a small amount, and a few will dry up altogether; there will be enough, however, to keep the flumes from drying and shrinking. It is probably not desirable to go beyond Kamalo Gulch for the purpose of collecting water for the region of the gap. Beyond this point the summit region is very precipitous and the expense of construction and maintenance would be very great.

The system of collection is combined with a system of storage by which part of the waters of the rainy season will be stored for summer use. A number of reservoir sites have been selected and surveyed which, it is believed, will be tight and satisfactory.

Referring to the data given above under "Running streams," the following amounts are believed to be available in the different gulches at elevations given below:

	210 days (Nov. 1-June 1).		60 days (June 1-Aug. 1).	
	Gallons per 24 hours.	Cubic feet per second.	Gallons in 24 hours.	Cubic feet per second.
Waihanau	3,250,000	5.02	1,000,000	1.55
Waialeia	300,000	.46	100,000	.15
Waikolu	1,250,000	1.93	300,000	.46
Kahapakai	250,000	.39	150,000	.23
Mokamoka	200,000	.31	100,000	.15
Luahine Fork	200,000	.31	75,000	.12
Kamiloloa	275,000	.43	100,000	.15
Makakupaia	425,000	.66	150,000	.23
West Fork Kawela	200,000	.31	50,000	.08
East Fork Kawela	1,200.000	1.86	300,000	.46
Total	7,550,000	11.68	2,325,000	3.58

This gives a total for two hundred and seventy days of 1,725,000,000 gallons (230,500,000 cubic feet). During the remaining months of the year there will be a varying flow less than 2,000,000 gallons (3.09 cubic feet per second), which may be considered to offset losses by leakage and evaporation. Assuming 500 acres to be irrigated with 5,000,000 gallons a day (7.74 cubic feet per second), or 1,825,000,000 gallons (244,000,000 cubic feet) a year, which amount certainly is ample, a storage capacity of about 577,000,000 gallons (77,000,000 cubic feet) is required in this case to supply about 480 acres with a steady flow of 4,800,000 gallons in twenty-four hours (7.43 cubic feet per second). During part of the winter months the full amount of water is not needed and consequently any increased storage capacity will increase the area which can be irrigated. The water is to be taken out as follows:

Waikolu.—Elevation of dam 3,600 feet; 4,500-foot flume, 2 by 1½ feet; grade 10 feet per mile; capacity 3,000,000 gallons (4.64 cubic feet per second); to cross gap at head of Makakupaia with 2,000 feet of 10-inch riveted pipe, and discharge in Kamiloloa. Probably too much loss of water would result by allowing water to run down into Makakupaia Fork.

Kawela.—Elevation of damming place 3,220 feet; 15,000 feet of flume to Makakupaia Fork; grade 10 feet per mile; capacity 8,000,000 gallons (12.38 cubic feet per second); size 2 by 3 feet; to dump water over edge of canyon into Makakupaia Fork; crosses Onini Gulch in siphon.

Makakupaia.—Elevation of dam 2,650 feet; 17,000 feet to Hunter's cabin; grade 10 feet per mile, dumping water in upper East Fork of Luahine Gulch at elevation of 2,600 feet; capacity 16,000,000 gallons (24.76 cubic feet per second); size 3 by 4 feet; crossing tributary gulches of Kaunakakai Gulch in siphons and receiving tributary flume from Kamiloloa and Waikolu.

Kamiloloa.—Elevation of dam 3,050 feet; 4,500 feet of flume, 2 by 2½ feet carrying; capacity 5,000,000 gallons (7.74 cubic feet per second); sharp grade,

Luahine Fork.—The water from the Makakupaia ditch is dumped into East Fork of Luahine. The latter is dammed at an elevation of 2,350 feet; 9,500 feet of flume to Kahapakai; size 3 by 4 feet; grade 20 feet per mile; capacity 20,000,000 gallons (30.94 cubic feet per second); crossing Mokamoka Fork and West Fork Luahine in siphons, receiving their flows in 2 by 1 foot tributary flumes; dumps at an elevation of 2,300 feet in Kahapakai.

Waialeia.—Damming place at an elevation of 2,760 feet; 4,000-foot flume 14 by 12 inches; 10-foot grade; dumping into Waihanau; capacity 1,000,000 gallons (1.55 cubic feet per second).

Waihanau.—Damming place at an elevation of 2,046 feet; 4,200-foot flume, 2½ by 3 feet; grade 10 feet per mile; capacity 10,000,000 gallons

(15.47 cubic feet per second); 400 feet of tunnel; dumping water into Kahapakai.

Kahapakai.—Damming place at an elevation of 2,000 feet; 3,000-foot flume, 3½ by 4 feet; capacity 30,000,000 gallons (46.42 cubic feet per second); grade 20 feet per mile; dumping into reservoir No. 1 at Meyers Lake.

From reservoir No. 1 there are several ways by which the water can be conducted down to the lower reservoir sites. The simplest would be to let it run down Meyers Creek to an elevation of 1,100 feet, whence it could be taken to the reservoirs in a ditch. This will, however, almost certainly cause large losses, which can not be afforded. A better plan would probably be to let it down to an elevation of 1,600 feet—that is, 300 feet below the reservoir—whence it can be conducted by a sharp-grade flume across the gap below the reservoir and thence to the head of the flat gulch in which the big reservoirs are located. This gulch, it is believed, is fairly tight; at any rate it is worth trying. Should the losses in this gulch be too large it will be necessary to construct a series of ditches at low grade connected with sharp drops which will conduct the water down to the reservoirs. It should be mentioned that all parts of the system are easily accessible. A wagon road extends from Kaunakakai to the gap at Kaohu station above reservoir No. 1; another road is built from Kaunakakai to Waikolu. Still another can be constructed at very slight cost from Kaunakakai by way of Makakupaia station to the headwaters of Makakupaia, and to the edge of the canyon above the West Fork of Kawela. In places the flumes will be difficult to build, but there do not appear to be serious obstacles in any place.

The required storage capacity, 577,000,000 gallons (77,000,000 cubic feet), is to be obtained as follows:

The highest reservoir is known as Meyers Lake, a small natural pond dammed to some extent by Mr. Meyer. It consists of two basins which can readily be dammed to contain 160,000,000 gallons (21,000,000 cubic feet). The elevation is about 1,900 feet. The site is excellent; the ground is evidently very tight and evaporation slight. Considerable wave action may be expected and the main dam must be riprapped and protected by a break water of logs. Abundant and excellent dam material, clayey, decomposed soil close at hand. Large quantities may be loosened by bank blasting. Two different schemes are proposed; if only the lower basin which drains towards Meyers Gulch is utilized, the capacity will be reduced to 91,000,000 gallons (12,000,000 cubic feet). If both basins are utilized they must be connected by a drain or siphon. The upper basin drains toward the north by means of a narrow cut which must be filled by a dam.

Dam No. 2 and No. 3 are natural basins at elevations of about 900 to 1,000 feet, apparently entirely tight and in their present state ready to receive water. They are situated about 2 miles west-north-

west of Meyer's ranch on the broad grassy ridge south of Eleuweuwe Point. They must be emptied by means of siphon pipes or drain tunnels.

Most of the gulches and creeks of the island have a very steep grade. Among the exceptions to this rule are the three gulches discharging on the north coast over the 1,000-foot pali, 2 or 3 miles north of Middle Hill. The water courses are from 2 to 4 miles long and meander with relatively low grade through the grassy rolling country here continuing out to the very edge of the pali. Their valleys are from about 100 feet deep up to 800 feet wide; their sides, as a rule, grassy and covered by clayey soil. Receiving but little precipitation they contain but little water, even during heavy rains and are thus excellently adapted for storage. Water can be stored in all three at elevation of from 800 to 1,000 feet. The most southerly of these creeks, flowing just south of Eleuweuwe Point, is best adapted for reservoir sites. There is no difficulty in carrying the stored water out from the reservoirs and down toward the cane lands. Four reservoirs were planned on this creek, though one of these, No. 5, may be dispensed with as the desired capacity is obtained without it. The dams must be carefully constructed of the abundantly available clayey soil, and I believe that the reservoirs will be found water-tight. They are calculated to 10 feet on top with a slope of 3:1 on both sides The surveys for these dams were made for me by Mr. E. Pope, at that time one of the surveyors of the American Sugar Company.

List of reservoirs.

No.	Capacity.		Height of dam.
	Gallons.	*Cubic feet.*	*Feet.*
1 (Meyers Lake)	160,000,000	21,389,000	30
2	62,000,000	8,288,000	(a)
3	73,000,000	9,758,500	(a)
4	117,000,000	15,640,500	54
5	138,000,000	18,448,000	54
6	189,000,000	25,266,000	54
7	100,000,000	13,368,000	52
Total	839,000,000	112,158,000	

[a] Natural basin.

From the reservoirs at an elevation of 800 feet the water is easily conducted by ditches and drops in shallow ravines to an elevation of 450 feet, the height of the gap, whence it can be applied to any part of the cane lands desired. The distance from the reservoirs to the cane lands is from 2 to 4 miles. It is easily understood that it is not necessary to construct this whole system outlined above at once. The Waihanau, Waialeia, Kahapahai may be first utilized together with reservoirs No. 1 and No. 2 or No. 7. The results of this system, which will irrigate at least 175 acres, will indicate the success to be expected from the installation of the whole system.

In conclusion it may be estimated that collecting and storing the running streams as outlined above will cost about $120,000 and the water collected amounts to a steady supply of nearly 5,000,000 gallons a day (7.74 cubic feet per second) during the whole year. The utilization of this water will interfere but little with the supply to be expected from pumps at sea level.

If it were found practicable to use the lands for cultivation of fruit trees and vines, this quantity of water—5,000,000 gallons in twenty-four hours (7.74 cubic feet per second)—would easily be sufficient to irrigate 1,000 acres. In view of the strong winds prevalent over the area containing good soil such culture may, however, be difficult. Experiments in this direction would be desirable.

In order to develop the water supply by catching some of the underground flow which otherwise would come out at elevations lower than the point of collection, tunnels might be driven at Waihauau, Waialeia, and Waikolu into the hill perpendicularly to the direction of the drainage, just above the damming place and in both directions from the creek; it is rather probable that notable amounts will thus be collected by comparatively short tunnels, say 100 or 200 feet in length.

Similar tunnels at the places where Kawela and Makakupaia forks are caught are not advisable.

Wailau and Pelekunu.—Referring to previous pages, it is estimated that Wailau has a minimum flow of 8,000,000 gallons (12.38 cubic feet per second) and Pelekunu of 7,000,000 gallons (10.83 cubic feet per second), both at an elevation of 600 feet; but measurements during the driest time of the year are necessary to confirm these figures. Only the minimum supply can be considered, for the high-level irrigation system proposed above has exhausted the greater part of storage capacity available.

The utilization of the water supply of these streams involves (1) a high-level ditch reaching the cane lands at an elevation of 450 feet and (2) long tunnels to bring the water to the south side of the island, the northern coast being entirely impracticable. Both ditch and tunnel will be very expensive.

There are two possibilities: (1) Utilization of Wailau alone; (2) utilization of Pelekunu and Wailau.

By the utilization of Wailau alone 8,000,000 gallons (12.38 cubic feet per second) of water will be obtained, and to this must be added water which will be found in the tunnel. The latter quantity is very doubtful, but will probably amount to several million gallons. The tunnel will tap Wailau, West Fork, at an elevation of 670 feet. The water from the East Fork will be added by ditch across gap south of Puu o Wailau. Length of tunnel to point in the canyon 1¼ miles above Dr. Morritz's house at Mapulehu (elevation 660 feet), 12,800 feet. From Mapulehu to the cane fields there will be 17 miles of conduit and flume,

with many siphons, the latter causing considerable loss of grade. Elevation of flume at cane fields, 450 feet. The expense of this undertaking would probably exceed $400,000. But it should be remembered that there are many things which may cause increased expense. Among these are the possibility that the tunnel may partly or wholly need cementing in order to become tight. Further, that loose strata may be met, which may largely increase the expense. Further, the difficulty of working the tunnel from both ends on account of descending grade and large quantity of water probably met with. Lastly, the difficulty of landing coal and machinery at Wailau. Time needed, if only worked from one end, three years.

By the utilization of Pelekunu and Wailau 14,000,000 gallons (21.66 cubit feet per second) should be secured, besides the large flow which will almost certainly be met in the tunnels. Ditches and flumes must be correspondingly enlarged, and a tunnel 14,500 feet long driven from Pelekunu to convey the water after it is collected from the different branches. The expense would be at least $800,000.

By tunneling the range from Kawela to Pelekunu the long and difficult conduit from Mapulehu to Kawela would be avoided and there would be also considerable saving of grade. The tunnel from Wailau (elevation 650 feet) to Pelekunu (elevation 635 feet) would be 15,000 feet long, while the tunnel from Pelekunu (elevation 635 feet) to Kawela (elevation 610 feet) would be 26,500 feet. All of the previously stated objections apply with still greater force. The enterprise would consume several years and require at least $1,200,000.

In conclusion, I consider it feasible to bring the water from Wailau and Pelekunu to the cane fields, but do not believe that the enterprise would be a paying investment.

UTILIZATION OF THE GROUND WATER.

This plan contemplates the pumping of water from shallow wells at suitable places along the coast up to a low flume, say 50 to 75 feet above sea level, and the further raising of it up to a level of 300 to 500 feet by means of reciprocating pumps. Considering the conditions fully outlined above, it is clear that a large volume of water, say 30,000,000 gallons (46.42 cubic feet per second), is not obtainable in any one place. The only way is to utilize all the resources as far as possible and to collect the water wherever found. It is true that this may be somewhat more expensive than if the water were found in one place, but it is the only plan possible, except if the supply from Wailau and Pelekunu be used.

When the ground water is concentrated about sea level, trenches, pits, or tunnels may offer the best means of collecting the same, the trenches and tunnels as a matter of course being extended parallel to the shore. Even in this case difficulties may occur, for the heavy pumping necessary to prosecute the work is apt to bring in sea water,

and leaks may be found which will admit large quantities of the same. If the water is more evenly distributed through the strata down to 30 or 40 feet below sea level, or if the bulk of it is found at the latter depth, sinking and tunneling become impracticable, for if it is attempted to keep the workings dry, the sea water, being under heavy pressure, is almost sure to find its way in. In such case groups of 14-inch bore holes should be used, and even when the water occurs at sea level they may become preferable. In these porous rocks the capacity of a single bore hole may be comparatively great and amount up to 1,000,000 gallons in twenty-four hours. There is great temptation to overdraw the capacity of wells, and this has been done both at Kaunakakai and at Kawela. Just as soon as a steady increase in salinity is noted the quantity drawn must be decreased. In these rocks one well has a large suction area. If one well will give 1,000,000 gallons (1.55 cubit feet per second), 20 wells surrounding it, say at the corners of each 40 feet square, will probably give at most 3,000,000 to 4,000,000 gallons (4.64 to 6.19 cubic feet per second). While many of these conditions seem discouraging, it should be borne in mind that one single well, that at Kaunakakai, has for over one year furnished a steady flow of water with a salinity of 85–90 grains per gallon, and that many similar places can doubtless be found along the coast.

At Palaau.—According to the data given above (wells and springs) there is probably a considerable amount of ground water available at Palaau at a depth of about 80 feet—how much is difficult to say; there is at least 1,000,000 gallons, possibly as much as 3,000,000. The wells bored have not been adequately tested, and this should first of all be done with the well and shaft near the deep well. If this will yield a steady stream for about a month or two of from 750,000 to 1,000,000 gallons (1.16 to 1.55 cubic feet per second) in dry season, I recommend that two or three more wells be sunk parallel to the coast, about 40 feet apart. If it should be found that these would yield 2,000,000 or 2,500,000 gallons (3.09 to 3.87 cubic feet per second) of water containing less than 100 grains of salt per gallon, this should be utilized to irrigate the bottom lands at Palaau, as well as part of the slopes above, which, though rocky, can be cleared and planted. About 1 mile of small flume will be needed. If the water is elevated to 100 feet by a reciprocating pump driven by electricity, it would require 44 horsepower, or 52 horsepower delivered at the motor. The salinity would be high—i. e., about 90 grains per gallon—and this may in the long run interfere with its use on the lowlands.

Cocoanut grove wells.—The 60-foot well at this place should be tested, which has not been done up to date. Should it be found that this well, with or without adjacent pit, will furnish 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) of salinity of 100 grains, this water may be used to irrigate the bottom lands adjacent, amount-

ing to 150 acres, less water being needed on these low-lying lands than on the higher ground. This would require 8 theoretical horsepower, or 10 delivered at the motor if electric power be used. Should the water prove too salt, water from Kaunakakai must be used.

Kaunakakai.—One well at Kaunakakai is clearly proved to be able to deliver a steady stream of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second). It is probable that 2,000,000 gallons (3.09 cubic feet per second) more may be obtained from shallow wells to sea level between this well and the so-called Risdon wells, 1 mile eastward.

Risdon wells.—These 20 wells have never been adequately tested, and their capacity is in doubt. Such incomplete tests as have been made are encouraging, and the conditions seem to indicate that they may furnish 2,000,000 gallons of water (3.09 cubic feet per second) at 80 grains of salinity. The water is contained in a well-defined stratum of porous rock from 9 feet to 34 feet below sea level.

Kawela.—Between Risdon station and the west boundary of Kawela the ground water does not appear along the coast in notable quantities, and the prospect of obtaining water from wells is not encouraging. But one-fourth of a mile east of Onini station very large springs appear on the beach, and I believe that there is 2,000,000 gallons (3.09 cubic feet per second) of ground water available at this place. The wells should be sunk at the foot of the bluff, just east of the rock point which extends to the sea. Preliminary exploration by means of pits or shafts would be necessary to decide at what level the water will be found; possibly most of it is held above sea level, but this is a point which can not be decided at present.

On the west side of Kawela Gulch for a distance of 2,000 feet from the creek a considerable amount of water is probably available. I think 3,000,000 gallons (4.64 cubic feet per second) can be secured here, but whether at sea level or 30 or 40 feet below it is impossible to say at present.

The flood plain of Kawela Gulch at present contains much water in its gravelly bed, but this amount will probably be notably diminished by the diversion of its headwaters into the irrigation system as proposed above. Nearly all of the recent well boring and pumping has been done on the east side of Kawela Gulch. The total quantity of water proved seems to be 4,500,000 gallons (6.96 cubic feet per second). Of this, 2,000,000 gallons (3.09 cubic feet per second) of 40 grains salinity have been shown to be available at wells Nos. 1, 2, and 3; 2,500,000 gallons (3.87 cubic feet per second) of 60 grains salinity may be considered proved at well No. 4, with its pit and tunnels, if the flow of salt water is shut off, which probably can be done by filling the salty bore hole with cement and constructing a cement wall around the leak in the southeast corner of the pit (see p. 44).

Tunneling at about 4 feet below water level has proved a difficult undertaking, and will become more so in the loose gravelly material which will be encountered near wells Nos. 6, 7, and 8. It would probably be better to run an open cut 6 feet wide in the bottom and 4 feet below water level in a line of about 15 feet south of the wells, thus collecting all of the ground water available at sea level into one central station, whence the water could be pumped. But to this must be added such amounts of the ground water as is stored in lower strata, as, for instance, 55 feet below the surface at well No. 3. This deeper water may be secured by connecting the bore holes with the main cut at its level—i. e., 4 feet below the sea level—but each bore hole must first be very carefully tested as to capacity and lowering of water level. If necessary, the open cut must be extended west of well No. 1, and a tunnel run through the bluff of well No. 9. It is almost impossible to outline a plan which in its details can be strictly adhered to, for the conditions change almost from day to day and the work requires the personal supervision of a very skilled and experienced engineer. In conclusion, it is believed that 10,000,000 gallons (15.47 cubic feet per second) may be expected at Kawela, east of the creek, and 3,000,000 gallons (4.64 cubic feet per second) west of the same. At Kamalo a quantity of water almost equal to that at Kawela may be expected, and a few million gallons may doubtless be obtained at intervals between Kamalo and Mapulehu.

To collect these waters will doubtless prove an expensive undertaking, owing to the many small pumping stations. Should it be desired to pump a smaller quantity for purposes of irrigation along the coast, some of the small streams at high elevations could be used to generate electric power to drive the pumps below.

Recapitulation.—While the estimate of waters available below the surface is necessarily very uncertain and difficult, I should place the probable amounts as follows:

Probable amount of water available.

	Million gallons per 24 hours.	Cubic feet per second.
Palaau	3	4.64
Cocoanut grove wells	1.5	2.32
Kaunakakai	3	4.64
Risdon wells	2	3.09
Onini Station	2	3.09
Kawela (west)	3	4.64
Kawela (east)	10	15.47
High-level irrigation system	4.8	7.43
Total	29.3	45.32

ELECTRIC POWER AVAILABLE.

As stated before, the irrigation system from the running streams outlined above should furnish at an elevation of 800 feet a steady supply of 4,800,000 gallons a day (7.43 cubic feet per second), or 3,333 gallons a minute. If the water is applied below 425 feet on the south slope of the gap, 375 feet of fall will be available, giving a theoretical horsepower of 314, which if converted into electrical power by means of Pelton wheel and dynamo and transmitted with high potential to Kawela should be sufficient to raise 13,000,000 gallons 66 feet; length of pressure pipe, 15,000 feet; length of transmission to Kawela, 10 miles. The greatest item of cost is the pressure pipe, which should be 14 inches in diameter, riveted, and of wrought iron, and which would not cost less than $50,000. The transmission would offer no difficulties, nor would the loss in transmission with high voltage be large. The great cost of pressure pipe diminishes the value of this proposition. More electric power could be obtained by utilizing the upper reservoir, which has a capacity of 160,000,000 gallons (247.56 cubic feet per second). Quantity of water available, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second), or 700 gallons per minute; fall available, 700 feet; total theoretical horsepower available, 123; horsepower available at pumps 5 to 10 miles distant, 75. Pressure pipe from reservoir to power station in Meyers Gulch, at elevation of 1,100 feet, would be 10,000 feet long; diameter of 8 inches should be sufficient. Here, again, the pressure pipe forms the principal item of cost, being not less than $15,000.

This proposition is more favorable, but still very expensive in comparison with the advantages obtained. On the whole, it seems more advisable to depend upon steam for motive power.

Electric power from Pelekunu, Wailau, and Halawa.—According to a preliminary report by Mr. M. M. O'Shaughnessy, dated December 5, 1899, the following approximate power could be generated by utilizing these streams:

Stream.	Normal flow (gallons per 24 hours).	Cubic feet per second.	Fall available for power	Horsepower (theoretical).
Halawa	5,000,000	7.74	300	263
Wailau	10,000,000	15.47	400	701
Pelekunu	5,000,000	7.74	200	210
Waikolu	3,850,000	5.96		

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